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Environmental Assessment

Waste Treatment Facility

OWMC
Ontario Waste Management Corporation

A provincial crown corporation.

TECHNOLOGIES AND SYSTEMS FOR TREATMENT AND DISPOSAL OF SPECIAL WASTES IN ONTARIO

Final Report to
Ontario Waste Management Corporation

Arthur D. Little of Canada Limited
ADL REF: 53245

October 2, 1986

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1886

Mr. Carl Finch
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Dear Carl:

Arthur D. Little is pleased to submit the enclosed final report entitled "Technologies and Systems for Treatment and Disposal of Special Wastes in Ontario," dated October 2, 1986.

On behalf of Arthur D. Little, I thank you for the opportunity to conduct this challenging assignment. Please feel free to call on us at any time for further assistance with OWMC's Facilities Development Program as it moves forward.

Sincerely,

Jeffrey M. Bass

Jeffrey M. Bass

Enclosure

Brussels
Cambridge
Houston
London
Los Angeles
Madrid
Mexico City
Milan
Paris
San Francisco
São Paulo
Singapore
Tokyo
Washington
Wiesbaden

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EXECUTIVE SUMMARY

PURPOSE

The Ontario Waste Management Corporation (OWMC) is a provincial Crown agency formally created in July 1981 by the Ontario Legislature. OWMC's primary responsibility is to establish and operate a liquid industrial and hazardous waste ("special waste") management facility in Ontario. As part of its work program, OWMC has identified technologies and developed general systems for the treatment and disposal of special wastes. OWMC defines "systems" as alternative groupings of preferred technologies able to perform complete treatment and disposal of all special waste which may be received at the facility.

The Arthur D. Little, Inc. was retained by OWMC to review and update its previous work. The specific objectives of this study were to:

1. Review and update previous OWMC work on alternative technologies, system options and selection criteria.
2. Review, re-evaluate and confirm or modify the waste management system and associated technologies generally preferred by OWMC.
3. Document the findings and present them in a report.

SCOPE

To accomplish the objectives, the following tasks were undertaken:

1. Review previous OWMC work on alternative treatment and disposal technologies, systems options, and selection criteria, with particular emphasis on the 1982 Proctor & Redfern "Generic Process Technologies Studies."(1)

2. Develop an updated list of generic technologies suited to treatment and disposal of special waste and update the information on these technologies given in "Generic Process Technologies Studies."(1)

3. Identify the generic technologies which are proven according to OWMC's definitions.

4. Establish waste/technology combinations which identify the types of waste treatable by each proven technology.

5. Develop criteria, based on OWMC's goals, for use in evaluating waste/technology combinations.

6. Develop a methodology for ranking waste/technology combinations according to how well they meet the evaluation criteria.

7. Describe the proven technologies according to the information required for evaluation by the criteria.

8. Evaluate the proven technologies and identify the highest ranking waste/technology combinations.

9. Develop system options by combining modules of proven technologies which together are capable of treating all types of wastes which may be received by OWMC.

10. Evaluate system options based on the component technologies and on the overall features of the systems themselves.

11. Prepare a fully documented report describing the work and providing conclusions and recommendations regarding the acceptability of the preferred system in relation to other possible conceptual systems.

METHOD

The methods used to accomplish the tasks included in the Scope were as follows:

1. Review Previous OWMC Work on Technologies, System Options and Selection Criteria

Arthur D. Little staff, knowledgeable in treatment and disposal technologies for special waste, reviewed all the documents provided by OWMC regarding technologies, system options and selection criteria.

2. Develop Updated List of Generic Technologies, and Updated Technology Information

The August 1982 report, "Generic Process Technologies Studies,"(1) prepared for OWMC by the Proctor & Redfern Group, served as a point of departure for developing an updated list of generic technologies for the treatment and disposal of special wastes. The sources used to update the list of technologies and the information contained in the Proctor & Redfern report included published literature, telephone interviews with users and vendors of special waste treatment technologies, and in-house files on previously conducted field visits to operating special waste treatment/disposal facilities. Updated information on each technology is provided in Appendix C.

3. Identify Proven Generic Technologies

The list of generic technologies was screened according to OWMC's definitions of "proven" (given in Appendix D). Examples of each proven technology were sought through telephone interviews with technology vendors and users. Technologies for which suitable examples could not be found were considered to be unproven. Only proven technologies were considered in the remainder of the study.

4. Establish Waste/Technology Combinations

Waste types were defined according to the University of California at Davis (UCD) waste classification scheme. Each UCD category was assigned to the technologies capable of treating the waste type described by that category (see Appendix A). Waste/technology matchings were made by Arthur D. Little staff based on experience, technology information in the published literature, and waste information from the descriptions of the UCD categories found in Appendix A.

5. Develop Evaluation Criteria

Technology evaluation criteria were developed by Arthur D. Little, in consultation with OWMC staff, based on OWMC's goals and on draft criteria previously developed by OWMC. Each criterion was broken down into "measures," which could be applied to determine how well a technology met the overall criterion. The performance of a technology with regard to each measure can be rated as "excellent," "good," or "fair," according to the descriptions provided in the criteria ratings.

6. Develop Ranking Methodology

A standard analytical technique was used to determine the relative value to OWMC staff of each criterion, and of each excellent, good and fair rating. Scores were determined for each excellent, good and fair rating and scaled so that the score for an ideal technology would be 100.

7. Describe Proven Technologies

Each technology was described briefly in terms of the evaluation criteria. The information used to describe the technologies was derived from the published literature, interviews with users and vendors, and analysis based on the experience of the Arthur D. Little team.

8. Evaluate Waste/Technology Combinations

The information provided in the technology descriptions was used to rate each technology as excellent, good, or fair according to the evaluation criteria and to generate a numerical score for each technology. The numerical scores were converted to letter grades to reflect the uncertainties inherent in the quantitative ranking methodology. The impact of these uncertainties on the technology rankings was further evaluated by means of a sensitivity analysis. The output of the evaluation was a list of the highest ranking waste/technology combinations for use in system development.

9. Develop System Options

The first system was developed by assigning each waste type to the highest ranking applicable technology. Discharges requiring further treatment were assigned to technologies already in the system. Two other systems were developed by modifying the overall characteristics of the first system. A fourth system was developed independently of the other three based on conventional European practice using the system generally preferred by OWMC as a model.

10. Evaluate System Options

System options were evaluated from two perspectives. First, the characteristics of the component technologies in each system were assessed, according to the technology evaluation procedure described previously. Second, the system options were compared in terms of the overall features of each system. Environmental factors were considered in each phase of the evaluation.

11. Report Preparation

All of the work described above, including findings, conclusions and recommendations, is summarized in this report.

PREMISES

This report is based on the following information, directives and guidelines provided to Arthur D. Little by OWMC.

1. Radioactive wastes and those wastes which can be adequately dealt with by conventional methods used by public facilities such as municipal sewage treatment plants, municipal incinerators and municipal landfills are not included in this study.

2. Generic technologies are included if, at a minimum, they can be designed and operated (either singly or in combination), to comply with existing and anticipated Ontario regulations, including transfers of liquid industrial wastes, wastewater discharges, and air emissions.

3. Only proven technologies are included in the development of system options. Proven is defined as "commercially demonstrated to have performed reliably for a period of a least twelve months on a scale and in a manner comparable with that required for the OWMC facility."

4. Systems are defined as "alternative groupings of preferred technologies able to perform complete treatment and/or disposal tasks." Each system option combines modules of proven technologies which together are capable of treating all types of wastes that may be received by OWMC.

5. The waste types and quantities used for this analysis are defined in Appendix B. Waste types are defined by UCD category and by OWMC waste class.

6. Disposal technologies will only be used for inorganic solid, treated residues. All residues, except for incinerator slag, will be solidified prior to disposal.

7. Laboratory waste chemicals (UCD 513) will arrive at the facility in a lab pack, i.e., in small vials or containers prepackaged with absorbent material in a large container. Organic laboratory waste will be destroyed by incineration. Inorganic laboratory waste will be analyzed and treated in accordance with the characteristics of the waste, on the assumption that a procedure will be developed which does not expose operators to unacceptable occupational risk.

8. Technologies will be described generically. Discussion of proprietary and site-specific variations is not within the scope of this study.

9. Only operating costs will be considered in the evaluation of technologies due to the difficulty of establishing comparable capital cost estimates for individual technologies, free from system infrastructure costs and without site-specific data.

10. The conceptual systems defined and analyzed include only technologies that are relevant to the purpose and intent of OWMC. Cement kiln incineration, for example, was excluded since manufacturing cement is outside of the scope of OWMC's mandate. Distillation was excluded since it would put OWMC in direct competition with private industry.

11. Only treatment and disposal technologies for special wastes are considered. Source reduction, recycling, recovery and reclamation technologies are not within the scope of this study.

12. Disposal options are being evaluated by others. The detailed, site-specific information necessary before making a final selection is beyond the scope of this report. Therefore, although disposal technologies have been ranked in the technology evaluation portion of the report, OWMC's

preferred disposal option (engineered landfill) has been assumed in the development and comparison of system options.

13. Effluent disposal options, including deep well injection, evaporation and total solidification, are being independently reviewed by OWMC.

POSTULATES

The following assumptions were made by Arthur D. Little in carrying out the scope of work:

1. All technologies will be applied in accordance with standard good operating practices and in compliance with all existing and anticipated regulations. In addition, all technologies will be operated in a way that will maximize protection of worker health and safety and minimize adverse effects on human health and the environment during normal operation and in the event of abnormal occurrences.

2. The facility will have an adequate and established emergency response program.

3. Although some technologies have the potential for energy recovery, operating costs presented do not include an energy credit.

4. Mixed organic and inorganic waste is treatable by the same set of generic technologies that are capable of treating all of the UCD categories. All system options are therefore able to treat mixed waste.

5. Half of the paint sludge (UCD 454), paint sludge without heavy metals (UCD 455) and laboratory waste (UCD 513) listed in Appendix B is primarily organic, and half is inorganic.

6. A technology is applicable to a given waste type if either it (1) reduces the hazard of the stream, or (2) reduces the quantity of the stream. Recovery is not an objective of the OWMC project and is not considered treatment in this study.

7. Dilution with fresh water is not considered to be a process and cannot be used to pretreat wastes so that a technology is applicable. A waste is considered to be treatable only if it can be treated by a given process in significant concentrations. However, use of effluent streams from the process recycled back into the process as part of normal operations is not considered to be dilution.

8. Neutralization is assigned only to UCD categories which do not generate solid residuals when the pH changes. If solid residuals are produced, the UCD category is assigned to precipitation.

9. System options are developed by assigning wastes to technologies according to the UCD categories. In operation of the OWMC facility, waste assignments and transfers between technologies will be made according to the actual characteristics of the waste received.

10. For the purpose of evaluating system options it was assumed that quantity of discharge to air and water were the most important system features, followed by quantity of residuals to land disposal, quantity of waste in the secondary system, number of technologies in the system, and operating cost. Quantity, rather than quality, was used in evaluating system options since all systems will need to meet the same operating standards.

STATUS OF DATA

1. Waste Classification by UCD Categories

The waste classification system used in this report was developed by the University of California at Davis (UCD). OWMC has further organized the UCD categories into 14 waste classes, based on similarities in physical and chemical properties that are important in the determination of applicable treatment technologies. A listing of UCD categories is given in Appendix A and OWMC waste classes in Appendix B.

There are many instances where the UCD category does not give enough information to make clear-cut waste/technology assignments. Three examples are: (1) percentage of solids is not specified for sludges; (2) the strength of the acids is not specified for acidic wastes, so that the quantity of alkali required for neutralization is uncertain; and (3) some of the wastes included in the same UCD category may need to be treated by different technologies. Various assumptions were made, as specified in Appendix A, to handle difficulties with the UCD system. Any discrepancies between the assumptions made and the nature of wastes actually received by OWMC will be accounted for in facility operation.

2. Waste Quantities

The quantity of waste used for systems development was provided by OWMC for each UCD category (Appendix B). Changing these waste quantities could affect the conclusions and recommendations made since the quantity of waste treated by each technology was considered in developing and evaluating system options. For example, the quantity of waste received in UCD categories sent to incineration affects the quantity of gaseous emissions generated by the facility.

3. Generic Technologies

Technologies are described generically rather than by specific vendor or developer. In some cases, proprietary modifications to a generic technology may sufficiently change the technology so that it should be evaluated separately from the generic technology. Evaluation of the difference between proprietary variations of generic technologies will be handled during detailed facility design.

4. Proven Technologies

The list of proven technologies is subject to change as experience is gained with new technologies. Technologies which were not proven according to OWMC's definition by January 1, 1985, were considered unproven for the purposes of this report.

5. Environmental Assessment Act

Environmental concerns are addressed in the evaluation of individual technologies and of system options. The effect of the technologies on human health and the environment is considered in the technology evaluation criteria, and discharges to air, water and land are considered for system options. The evaluation in this report, however, is not site-specific and therefore does not address the particular concerns of the Environmental Assessment Act. The environmental assessment required by the Act will need to be undertaken by OWMC using the actual facility design at the selected site.

6. Cost Data

Operating costs were developed for each proven technology in 1985 Canadian dollars. The costs represent the incremental cost for the technologies to treat or dispose of the types of waste for which a technology is applicable using the quantities given in Appendix B.

Operating costs are used in the evaluation of individual technologies and system options. Facility infrastructure and capital recovery are not included in the cost estimates. Since the purpose for developing these costs was to compare system options for OWMC only, it would therefore be inappropriate to compare these technology and system costs to the costs or prices (for treatment and disposal services) at existing or proposed commercial facilities for treatment and disposal of special wastes.

MAIN FINDINGS

- There are 43 proven generic technologies for the treatment, storage and disposal of special wastes. These technologies can be divided into six functional groups: biological, physical, chemical, thermal, stabilization/solidification, and disposal technologies.

- There is at least one proven technology for each UCD waste category. There is no single proven technology applicable to all waste categories.

- Rotary kiln incineration is the only technology that is capable of treating all organic wastes, and it is the only option for some organic wastes. It is a necessary part of any system option which is to be capable of treating all waste types.

- Protection of worker and community health and safety is the most important criterion to OWMC; relative cost is the least important.

- The highest ranking technologies are those which involve simple physical separation and can be operated at room temperature and pressure in a closed system. The lowest ranking technologies are thermal and chemical destruction processes and land-based technologies which have the potential for off-site impacts due to abnormal events.

- Forty-six percent of the UCD categories are treatable by technologies with the highest ("A") ranking; 44% are only treatable by technologies with the lowest ("C") ranking.

- Overall, there are thousands of system options possible for treatment and disposal of all waste types expected to be received by OWMC.

- All systems are made up of a set of treatment technologies that treats primarily organics and another that treats primarily the inorganics.

- For optimized organic treatment, all organics are incinerated in the rotary kiln except for aqueous streams with less than 10% organics (UCD 225 and 226),[*] which are treated by activated sludge/powdered activated carbon, and oil/water emulsions which may contain up to 95% water (UCD 281, 282, 283 and 289) that are treated by emulsion breaking. By treating these organic streams separately, approximately 40,000 tonnes/year of air emissions (10% of the total) are avoided.

- Inorganic treatment consisting of five technologies (neutralization, precipitation, chemical oxidation, chemical reduction and solidification) best meets OWMC's objectives by optimizing the competing means of residual removal from the plant by air emissions, liquid effluents and land disposal.

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[*] It was assumed that most wastes classified as UCD 225 or 226 will have 1% or less organic residue.

CONCLUSIONS

- The system which best meets OWMC's goals and objectives (as described in this report) consists of rotary kiln incineration, activated sludge/powdered activated carbon and emulsion breaking of organic waste, and comprehensive physical and chemical treatment, including solidification, for inorganic wastes. This system (referred to as System 2) has the least amount of air emissions and quantity of residuals requiring treatment by the secondary system. It also generates 8% less liquid effluent than the system preferred by OWMC. Its drawback compared to the other systems is that it requires about 8% more land disposal and has a slightly higher operating cost than OWMC's preferred system.

- The conceptual system preferred by OWMC, consisting of rotary kiln incineration, comprehensive physical and chemical treatment, and engineered landfill, corresponds to conventional European practice for safe and efficient treatment and disposal of special wastes. In addition, emulsion breaking is used to reduce the load on the rotary kiln, and solidification is used for all residuals prior to land disposal. Although emulsion breaking and solidification are not normally included in Europe, they provide additional environmental protection since air emissions and potential for groundwater contamination are reduced. However, to a minor extent, System 2 is more effective in meeting OWMC's goals and objectives. It makes improvements over OWMC's preferred system in the most important system features (quantity of gaseous emissions and liquid effluent generated).

- The effectiveness of the conceptual system preferred by OWMC in meeting OWMC's goals and objectives might be improved by using activated sludge/powdered activated carbon for treatment of aqueous solutions with less than 10% halogenated or non-halogenated residues (UCD 225, 226). This decreases the amount of waste sent to the rotary kiln thereby decreasing gaseous emissions. The benefit of adding activated sludge/powdered activated carbon will depend on the quantity of waste received which is treatable by this technology.

- The effectiveness of the conceptual system preferred by OWMC in meeting OWMC's goals and objectives might be improved by solidifying rather than dewatering certain inorganic wastes. The main benefit of dewatering inorganic wastes is that it reduces the quantity of liquid sent to solidification, thereby reducing treatment cost and the quantity of material requiring land disposal. Solidifying these wastes directly, however, reduces liquid effluent by 8%, which is a more important objective than reducing cost or quantity sent to land disposal.

- If OWMC decides to select a zero discharge option, the choice between solidification and evaporation of liquid effluent is not clear-cut. Solidification of liquid effluent produces about 15% fewer gaseous emissions than evaporation, has fewer component technologies, and has about half as much waste in the secondary system. However, it sends nearly twice as many residuals to land disposal and is 50% more expensive. Although reducing gaseous emissions is a greater priority than reducing quantity to land disposal or operating cost, it is not clear whether a 15% decrease in gaseous emissions offsets a two-fold increase in land disposal and a 50% increase in operating cost.

- The content of the Proctor and Redfern "Generic Process Technologies Studies" is still basically correct except that cost estimates are out of date, certain emerging technologies are not covered, and wastes have been mis-assigned to technologies in some cases. Updated technology discussions are given in Appendix C.

RECOMMENDATIONS

- OWMC should consider adding activated sludge/powdered activated carbon for treatment of aqueous solutions with less than 10% halogenated and non-halogenated residues (UCD 225, 226). However, since information currently available on waste types and quantities is insufficient to determine how much waste would actually be suitable for treatment by this technology, it is recommended that this decision be made after start-up when more is known about the wastes that are actually received.

- OWMC should consider solidifying rather than dewatering inorganic solids and sludges, since this decreases the amount of liquid effluent generated.

- For each of the generic technologies to be used, vendor-specific variations should be investigated.

- The market survey data developed by OWMC should be analyzed further for available information on specific waste compositions, beyond the UCD categories. Depending on the quality and quantity of the information, the possibilities for material recovery should be examined and facility design and operation should be modified, as appropriate.

- Because of the importance of the abnormal events and normal operations criteria to the evaluation conducted in this study, the attainment of these criteria should be re-evaluated when the site and the precise system design is chosen. Different sites may be sensitive to different abnormal events or normal operations, and the results of this analysis may change if site-specific factors are considered.

- Development and demonstration of innovative treatment technologies is an active area of research in Canada and elsewhere. OWMC should update their list of proven technologies periodically to incorporate novel technologies when they become proven. As of the date of submission of this report in Fall 1986, for example, sequencing batch reactors and liquid ion exchange, both not proven as of January 1, 1985, may now be considered proven.

CHAPTER 1

BACKGROUND AND REPORT OVERVIEW

This chapter briefly summarizes previous OWMC work on alternative treatment technologies and system options for the management of special waste generated in the Province of Ontario. It also provides an overview of the remainder of this report.

PREVIOUS OWMC WORK

The principal reports previously published by OWMC on alternative technologies and systems include:

- Procter & Redfern Group, "Generic Process Technologies Studies," August 1982.
- Procter & Redfern Group, "European Tour," September, 1982 (reprinted February 1984).
- OWMC, "Facilities Development Process," Phase 3 Interim Report, May 1983.
- OWMC, "Facilities Development Process," Phase 3 Report, March 1984.

The "Generic Process Technologies Studies"(1) describe the operating characteristics and applications of 48 generic technologies for the treatment or disposal of special wastes. The technologies included are listed in Table 1.1.

TABLE 1.1

TREATMENT/DISPOSAL PROCESSES PREVIOUSLY EVALUATED BY OWMC CONSULTANTS

Biological Treatment Methods

Activated Sludge Process
Activated Sludge Process Using Pure Oxygen
Trickling Filters
Rotating Biological Contactors
Fluidized Bed Wastewater Treatment (Aerobic) Systems
Lagoons (Stabilization Ponds) and Aerated Lagoons
Composting
Landfarming
Powdered Activated Carbon - Activated Sludge Process
Anaerobic Digestion
Enzyme Treatment/Mutant or Adapted Microorganisms

Physical/Chemical Treatment Methods

Carbon Adsorption
Resin Adsorption
Centrifugation
Dehalogenation
Electrodialysis
Filtration
Hydrolysis
Ion Exchange
Neutralization
Chemical Oxidation
Precipitation, Flocculation and Sedimentation
Chemical Reduction
Reverse Osmosis
Ultrafiltration
Stripping
Solvent Extraction
Electrolytic Processes

Thermal Processing

Rotary Kiln Incineration
Multiple Hearth Incineration
Evaporation
Calcination/Cement Kiln Incineration
Liquid Injection Incineration
Fluidized Bed Incineration
At-Sea/Shipboard Incineration
Molten Salt Incineration
Wet Air Oxidation
Plasma Arc/Microwave Plasma Discharge

TABLE 1.1 (continued)

Solidification/Stabilization and Encapsulation

Cement Based Processes
Lime Based (Pozzolanic) Processes
Thermoplastic Techniques
Organic Polymer Processes
Glassification

Ultimate Disposal

Secure Landfill
Deep Well Injection
Underground Storage in Geologic Formations
Above Ground Storage
Warehousing

Source: Reference (1)

The "European Tour"(2) was a field study of operating systems for the management of special wastes in several European countries. Table 1.2 summarizes the special waste management systems in Europe and the treatment and disposal technologies used at each. In 1982, the OWMC "European Tour" team visited most of the listed facilities, except for those with an asterisk. The focus of the European tour was on systems; i.e., groups of technologies which collectively can perform complete treatment and disposal tasks for all types of wastes accepted by the facility.

The component technologies of the observed European systems were found to be consistent with the findings of the "Generic Process Technologies Studies"(1) and formed the basis for the initial facility system outlined by OWMC in the Phase 3 Interim and Final Reports.(3)(4) This system comprises:

- A rotary kiln incinerator for thermal destruction of combustible organic wastes.
- A comprehensive physical/chemical treatment plant, primarily for processing of inorganic and aqueous organic wastes.
- An engineered landfill for disposal of slag from the incinerator and all solid residuals generated by the facility.

The versatility of such a system for handling a wide range of waste types has been proven in Europe. In addition, OWMC's initial facility system uses emulsion breaking for certain organic wastes to reduce the load on the incinerator, and incorporates a solidification plant to treat all residues from incineration and physical/chemical treatment prior to disposal.

Based on a study of current disposition of special wastes generated in Ontario, OWMC has conservatively estimated that its facility would receive at least 50,000 tonnes of special wastes in its first year of operation. The Phase 3 Report(4) selects for preliminary design purposes a rotary kiln incinerator with a capacity of 30,000

TABLE 1.2

SPECIAL WASTE MANAGEMENT SYSTEMS IN EUROPE

Facility/Location	Technological System Components
HIM, West Germany	
- Biebesheim	2 Rotary Kiln Incinerators
- Frankfurt	Physical/Chemical Treatment
- Kassel*	Physical/Chemical Treatment
- Mainflingen*	Landfill (not operational)
- Klein-Seelheim*	Landfill
Kali und Salz AG Herfa-Neurode, West Germany	Geologic Isolation (underground salt mine storage and disposal)
SAKAB, Sweden	
- Norrtorp	Physical/Chemical Treatment Rotary Kiln Incinerator Above Ground Landfill Solidification
- Lovstad*	Solvent and Oil Recovery Incineration Collection Station
- Gothenburg*	Physical/Chemical Treatment Collection Station
- Unea*	Collection Station
- Helsinzburg*	Collection Station
Re-Chem International, Inc. Fawley, England	Refractory Lined Rail Car Incin. Physical/Chemical Treatment Landfill Copper Recovery Waste Oil Recovery
SARP Industries Limay, France	Liquid Injection Incineration Physical/Chemical Treatment Solidification Copper Recovery Oil Recovery
AVR Rotterdam, The Netherlands	Rotary Kiln Incinerator Physical/Chemical Treatment
WESTAB Duisburg, West Germany	Landfill Mobile Physical/Chemical Dewatering Collection Station

TABLE 1.2 (continued)

Facility/Location	Technological System Components
Bayer AG Leverkusen, West Germany	2 Rotary Kiln Incinerators Biological Wastewater Treatment Landfill
GSB, West Germany	
- Ebenhausen	2 Rotary Kiln Incinerators Physical/Chemical Treatment
- Schweinfurt*	Collection Station Liquid Injection Incinerator Landfill
- Gallenbach	Collection Station Landfill
- Geretsried*	Solvent Recovery
ZVSMM, Schwabach, West Germany*	Incinerator Physical/Chemical Treatment Landfill Collection Station

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* not visited by OWMC

Source: Reference (2)

tonnes per year to be operated on a continuous, seven-day schedule, and a physical/chemical treatment plant with a capacity to process 50,000 tonnes per year on a single shift, five-day per week basis.

The size of the rotary kiln incinerator is typical of units installed in both Europe and the United States. The physical/chemical treatment plant could process up to 120,000 tonnes per year of waste by operating on a continuous, five-day per week basis, giving the facility an initial design capacity of 150,000 tonnes/year.

OWMC has continued to keep abreast of operating systems as well as generic technologies for treatment and disposal of special wastes. OWMC conducted a second field investigation of European incineration facilities in October 1984. Further, OWMC has established a market assessment project to continually refine and update information on the types, quantities and sources of special wastes likely to be received by its facility.

REPORT OVERVIEW

This report summarizes the independent evaluation of systems capable of treating and disposing of all special wastes generated in the Province of Ontario. It also updates the "Generic Process Technologies Studies."(1) The remainder of the report is organized as follows:

- Chapter 2 updates the Proctor & Redfern list of generic technologies available for treatment and disposal of special wastes in Ontario, identifies those that meet OWMC's definitions of "proven," and establishes waste/technology combinations by identifying the waste types treatable by each technology.
- Chapter 3 evaluates the waste/technology combinations identified in Chapter 2. Evaluation criteria are presented which reflect OWMC's goals, and the technologies are

discussed according to the criteria. The waste/technology combinations are then ranked according to how well they meet the criteria.

- Chapter 4 develops and evaluates alternative system options. Each system is comprised of proven technologies which together are capable of treating all types of special wastes generated in the Province of Ontario.

- Chapter 5 presents conclusions and recommendations, based on the evaluation of the alternative system options.

Typical waste streams and residuals are listed by category in Appendix A and by OWMC waste class in Appendix B. Appendices C and D are provided in a separate volume. Appendix C summarizes the information used in ranking each proven technology, and updates the information on proven technologies from the "Generic Process Technologies Studies."(1) Appendix D gives detailed information on the technology scoring process.

CHAPTER 2

GENERIC TECHNOLOGIES FOR TREATMENT AND DISPOSAL OF SPECIAL WASTES

This chapter identifies generic technologies for treatment and disposal of special wastes. The technologies are listed by functional group (i.e., technologies that are based on similar scientific principles and that perform similar functions). Technologies which are proven, based on the definition established by OWMC, are specified. Waste/technology combinations are then established by considering the waste types treatable by each technology, using the University of California at Davis (UCD) waste categorization scheme. The principal findings presented in this chapter are:

- There are 43 proven generic technologies for the treatment, storage and disposal of special wastes. These technologies can be divided into six functional groups: biological, physical, chemical, thermal, stabilization/solidification, and disposal technologies.

- There is at least one proven technology for each UCD waste category. There is no single proven technology applicable to all waste categories.

- Rotary kiln incineration is the only technology that is capable of treating all organic wastes, and it is the only option for some organic wastes. It is a necessary part of any system option which is to be capable of treating all waste types.

IDENTIFICATION OF PROVEN GENERIC TECHNOLOGIES

Table 2.1 lists the generic technologies available for treatment and disposal of special wastes. This list was derived by OWMC and Arthur D. Little based on:

- Proctor & Redfern Group, "Generic Process Technologies Studies".(1)

- Files of published literature and other information on special waste treatment and disposal technologies, started by Arthur D. Little in 1975 to prepare the U.S. EPA report "Physical, Chemical and Biological Treatment Techniques for Industrial Wastes".(5) This report was later published as Unit Operations for Treatment of Hazardous Industrial Wastes.(6) The files have been maintained through regular review of key periodicals.(7)

- Knowledge derived from Arthur D. Little's ongoing professional activities in the treatment and disposal of special wastes.

- Proctor & Redfern Group, "European Tour," September 1982 (reprinted February 1984),(2) a report which describes special waste treatment and disposal technologies observed by OWMC and consultant staff in a tour of European facilities.

- Discussions among OWMC and Arthur D. Little staff about available literature, other sources of information, and technologies in use and under development. Field investigations conducted by OWMC in Canada, Japan, the U.S. and Europe were an important focus of the discussions.

TABLE 2.1

AVAILABLE GENERIC TREATMENT/DISPOSAL TECHNOLOGIES

Proven Technologies	Unproven Technologies
• Biological Treatment Processes	
Activated Sludge	Composting
Activated Sludge/Powdered Activated Carbon Treatment	Enzyme Treatment/Mutant or Adapted Microorganisms
Activated Sludge Using Pure Oxygen	*Sequencing Batch Reactor
Anaerobic Digestion	
Fluidized Bed Contactor	
Land Treatment	
Rotating Biological Contactor	
Trickling Filter	
Waste Stabilization Pond	
• Physical Separation Processes	
Air Stripping	*Electrophoresis
Carbon Adsorption	*Freeze Drying
Centrifugation	Liquid Ion Exchange
Dissolved Air Flotation	*Magnetic Separation
Electrodialysis	*Supercritical Fluid Extraction
Emulsion Breaking	
Evaporation	*Suspension Freezing
Filtration	*Zone Refining
Flocculation/Sedimentation	
Resin Adsorption	
Reverse Osmosis	
Solvent Extraction	
Steam Stripping	
Ultrafiltration	
• Chemical Treatment Processes	
Chemical Reduction	*Chlorinolysis
Chemical Oxidation	*Cavitation
Dehalogenation	Hydrolysis
Ion Exchange	*Supercritical Water Oxidation
Neutralization	UV/Ozonation
Precipitation	UV/Hydrogen Peroxide
Wet Air Oxidation	*Vertical Tube Wet Air Oxidation

TABLE 2.1 (continued)

Proven Technologies	Unproven Technologies
• Thermal Treatment Processes	*Calcination
	*Catalysis
Cement Kiln Incineration	*Fluid Wall Reactor
Fluidized Bed Incineration	*Infrared Electric Furnace
Liquid Injection Incineration	Molten Salt Incineration
Multiple Hearth Incineration	*Molten Glass Incineration
*Pyrolysis	Plasma Arc
Rotary Kiln Incineration	Microwave Plasma Discharge
• Solidification/Stabilization Processes	
Cement Based Processes	Organic Polymer Stabilization
Lime Based Processes	Thermoplastic Stabilization
Silicate Based Processes	
• Disposal Processes	
Deep Well Injection	RUMOD (underground rock storage)
Geologic Isolation	
Engineered Landfill	
Warehouse Storage	

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* Not included in Reference (1).

The generic technologies shown in Table 2.1 are subdivided in terms of:

- Functional group.
- Whether or not they are proven according to OWMC's definitions.

Functional groups are used to categorize technologies based on similar scientific principles and that perform similar waste treatment and disposal functions. The six functional groups, shown in Table 2.1, are defined as follows:

- Biological treatment technologies--Wastes are exposed to naturally-occurring, acclimated or genetically-engineered microorganisms capable of metabolizing organic chemical components, often to non-toxic compounds such as carbon dioxide and water.
- Physical separation technologies--These technologies separate waste streams into two or more components, each of which can be managed more appropriately than the combined waste stream. Physical processes may be used, for example, to separate solids from liquids, oil from water, or water from certain wastes (evaporation). Physical processes do not change the chemical identity of waste stream components.
- Chemical treatment technologies--Waste streams are treated with chemical reagents to produce products that are either less hazardous, non-hazardous, or easier to remove from the waste stream by subsequent processing.
- Thermal treatment technologies--Organic wastes are decomposed by burning at high temperatures to produce carbon dioxide, water vapor and other combustion products, which are generally non-hazardous or less hazardous than the original waste stream.

- Solidification/stabilization technologies--Treated waste residues or inorganic wastes are mixed with cement, silicates and/or lime-based material to form a solid product which leaches more slowly and generally produces a leachate that is less hazardous than that of the untreated waste.

- Disposal technologies--These technologies are intended to provide a permanent repository for the treated residues that remain after special wastes have been treated to the fullest extent possible by one or more of the above processes.

The generic treatment and disposal technologies identified in the study were screened according to whether they are proven. OWMC defines "proven" technologies as those commercially demonstrated to have performed reliably for a period of at least twelve months on a scale and in a manner comparable with that required for the OWMC facility. The definition of proven is presented in more detail in Appendix D. Table 2.1 identifies the generic technologies which were proven as of January 1, 1985. Only proven technologies are given further consideration in this report.

Technologies are listed generically in Table 2.1, rather than by specific vendor or developer, since proprietary variations of a generic technology accomplish the same objective. Evaluation of the differences between proprietary variations of generic technologies will be handled during detailed facility design. The generic listing presents certain difficulties in this study, particularly for proprietary vendor-specific process variations that are patented. Two important questions arise. First, do the patented or proprietary features change the technology sufficiently so that a generic description is inapplicable? Second, if a generic technology with new patented features has not been commercially demonstrated in accordance with the patent claims, should the technology be considered proven? For example, engineered landfill is a generic technology. The Rollins Vault can be classified as an engineered landfill technology. On the other hand, it is a patented technology that has not been commercially demonstrated in accordance with the OWMC definition of proven. To simplify the discussions in this report, proprietary modifications to generic technologies have not been identified. Specific vendors are not discussed, although in some instances a technology listed as generic (e.g., supercritical water oxidation) is in fact only offered by a single vendor.

ESTABLISHMENT OF WASTE/TECHNOLOGY COMBINATIONS

OWMC is committed to establishing a system for treatment and disposal of all types of special wastes generated in the Province of Ontario. By policy, OWMC will not dispose of wastes until they have been treated. For planning purposes, therefore, OWMC must consider the relative advantages and disadvantages of all proven technologies, taking into account the type of waste that is expected to be received.

Tables 2.2, 2.3, and 2.4 summarize the applicability of the proven generic technologies to each type of waste expected to be received at the OWMC facility. Specific waste types are identified in the Tables by UCD category (see Appendix A) and by OWMC waste class (see Appendix B). Separate tables are shown for waste organics (Table 2.2), inorganic aqueous solutions (Table 2.3), and inorganic solids and sludges (Table 2.4) because there is very little overlap in the technologies applicable to each of these three basic waste types. For instance, rotary kiln incineration is applicable to all organic wastes (Table 2.2), but it is not suitable for inorganic aqueous wastes or inorganic solids and sludges (Tables 2.3 and 2.4). Neutralization, precipitation and ion exchange are applicable to many categories of inorganic aqueous wastes but to no organic wastes insofar as can be judged from the definitions of the UCD categories. The choice of technologies for treating inorganic solids and sludges, as shown in Table 2.4, is essentially limited to dewatering (by centrifugation or filtration, possibly combined with flocculation/sedimentation to facilitate solids/liquid separation) and solidification.

TABLE 2.2

ORGANIC WASTES: APPLICABLE TECHNOLOGIES

UCD CATEGORY:	211	212	213	214	215	216	217	221	222	223	224	225	226	227	228	241	242	243	244	245	247	248	252	254
OWMC CLASS:	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	12	13	7	7	7	1	1	1	8
TECHNOLOGIES:																								
Rotary Kiln Incin.	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Fluidized Bed Incin.	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Pyrolysis																					●	●	●	
Liquid Injection Incin.			●			●	●		●	●	●	●	●	●	●		●							
Wet Air Oxidation												●	●	●									●	●
Activated Sludge/Powdered Activated Carbon												●	●											
Land Application																						●	●	
Anaerobic Digestion												●												
Other Biological												●												
Air Stripping																								
Carbon Adsorption												●	●											
Resin Adsorption												●	●											
Centrifugation	●	●		●	●			●																
Dissolved Air Flotation																								
Emulsion Breaking																								
Flocculation/Sedimen.																								
Solvent Extraction														●	●									
Steam Stripping																								
Dehalogenation																	●							

TABLE 2.2 (continued)

UCD CATEGORY:	257	258	261	262	263	264	281	282	283	284	285	286	288	289	416	446	447	454	455	512	513	521	523	528	531	532
OWMC CLASS:	1	8	1	8	1	5	3	5	4	5	5	5	5	4	7	1	5	8	8	14	7	14	1	14	14	12
TECHNOLOGIES:																										
Rotary Kiln Incineration	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Fluidized Bed Incineration	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●		●	
Pyrolysis	●		●		●	●		●		●	●	●	●			●	●	●	●				●		●	
Liquid Injection Incineration							●																			
Wet Air Oxidation									●					●			●						●			
Activated Sludge/ Powdered Activated Carbon																										
Land Application								●	●	●	●	●											●			
Anaerobic Digestion																										
Other Biological																										
Air Stripping																										
Carbon Adsorption																										
Resin Adsorption																										
Centrifigation									●				●										●			
Dissolved Air Flotation									●																	
Emulsion Breaking							●	●	●					●												
Flocculation/Sedimentation				●																						
Solvent Extraction													●													
Steam Stripping																										
Dehalogenation																										

UCD classes and OWMC categories are described in Appendix A and B, respectively.
Comments on waste/technology assignments are given in Appendix A.

TABLE 2.3

INORGANIC AQUEOUS WASTES: APPLICABLE TECHNOLOGIES

UCD CATEGORY:	111	112	113	121	122	123	131	132	133	141	142	143	145	146	147	251	513*
OWMC CLASS:	6A	6A	6A	6A	6A	6A	6A	6A	6A	6A	6A	10	6A	10	6A	6A	7
TECHNOLOGIES:																	
Centrifugation										●	●		●			●	
Electrodialysis										●	●		●			●	
Filtration										●	●		●			●	
Flocculation/Sedimen.										●	●		●			●	
Neutralization			●			●											
Precipitation	●	●		●	●		●	●	●	●	●						
Chemical Oxidation												●		●	●		
Chemical Reduction												●				●	
Evaporation										●	●		●				
Reverse Osmosis										●	●		●				
Ion Exchange	●			●						●	●						
Solidification										●	●		●				

UCD classes and OWMC categories are described in Appendix A and B, respectively.
Comments on waste/technology assignments are given in Appendix A.

* Inorganic laboratory waste will be analyzed and reclassified in other UCD categories, as appropriate.

TABLE 2.4

INORGANIC SOLIDS AND SLUDGES: APPLICABLE TECHNOLOGIES

UCD CATEGORY:	151	152	165	167	417	431	433	441	443	444	445	454	455	509*	518
OWMC CLASS:	11	11	11	11	11	6B	6B	11	11	6B	6B	8	8	14	11
TECHNOLOGIES:															
Chemical Oxidation										●					
Centrifugation					●	●	●	●	●		●	●	●		
Filtration					●	●	●	●	●		●	●	●		
Flocculation/Sedimen.					●	●	●	●	●		●	●	●		
Solidification	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Disposal Technologies														●	

UCD Classes and OWMC Categories are described in Appendix A and B, respectively.

Comments on waste/technology assignments are given in Appendix A.

* UCD 509 (gas cylinders) is not accepted by OWMC

The UCD waste classification system simplifies reality by placing wastes in a limited number of categories. As a result, specific assumptions were made regarding the types of waste expected to be received in each UCD category. These specific assumptions are noted in Appendix A in cases where interpretation of the description of the UCD category is particularly difficult. For categories which are not footnoted in Appendix A it is assumed that the description of the UCD category is accurate and is adequate to make a reasonable determination of applicable technologies.

In addition to these specific assumptions, several general assumptions were made in making waste/technology assignments:

- A technology is applicable to a given waste type if either it (1) reduces the hazard of the stream, or (2) reduces the quantity of the stream. Recovery is not an objective of the OWMC project and is not considered treatment in this study.

- Dilution with fresh water is not considered to be a process and cannot be used to pretreat wastes so that a technology is applicable. A waste is considered to be treatable only if it can be treated by a given process in significant concentrations. However, use of effluent streams from the process recycled back into the process as part of normal operations is not considered to be dilution.

- Neutralization is applicable only to waste streams where the pH change does not cause the precipitation of metals. If metals are removed, the waste is assigned to precipitation.

Any discrepancies between UCD categories and the nature of wastes actually received by OWMC will be accounted for in facility operation.

One particular problem caused by the UCD classification system is that three waste categories (paint sludge-UCD 454; paint sludge without heavy metals-UCD 455; and laboratory wastes-UCD 513) may include organic or inorganic waste (e.g. solvent based or water based paint sludges) or a combination of the two (e.g. solvent based paint sludge with inorganic pigments). Wastes received from the categories would be treated by different technologies, depending on the quantity of organics present. It is assumed in Tables 2.2 to 2.4 that half of the waste received in each category is primarily organic and half is inorganic.

The information in Tables 2.2, 2.3 and 2.4 establishes the waste/technology combinations that are discussed in Chapter 3. Waste/technology combinations, rather than individual technologies, were evaluated, since it was only meaningful to compare technologies that can be used to treat the same waste. For example, rotary kiln incineration, fluidized bed incineration, pyrolysis, centrifugation and solvent extraction can be compared for the treatment of oily wastes with heavy metal contaminants (UCD 288), but these technologies cannot be compared directly with neutralization since they do not treat any of the same waste.

CHAPTER 3

EVALUATION OF WASTE/TECHNOLOGY COMBINATIONS

This chapter evaluates the waste/technology combinations established in Chapter 2. The waste/technology combinations are described and evaluated with respect to criteria developed by Arthur D. Little in conjunction with OWMC staff. A standard ranking procedure is employed to quantify the results of this evaluation and identify the waste/technology combinations which best achieve the criteria and OWMC's goals. These higher ranking waste/technology combinations were used to develop the system options discussed in Chapter 4. The principal findings presented in this chapter are:

- Protection of worker and community health and safety is the most important criterion to OWMC; relative cost is the least important.

- The highest ranking technologies are those which involve simple physical separation and can be operated at room temperature and pressure in a closed system. The lowest ranking technologies are thermal and chemical destruction processes and land-based technologies which have the potential for off-site impacts due to abnormal events.

- Forty-six percent of the UCD categories are treatable by technologies with the highest ("A") ranking; 44% are only treatable by technologies with the lowest ("C") ranking.

EVALUATION CRITERIA

Criteria for evaluating waste/technology combinations were developed to reflect OWMC's three stated goals:(4)

- Minimize risk to human health.

- Minimize environmental impacts.

- Minimize financial costs to OWMC and the people of Ontario.

Criteria more specifically related to definable characteristics of waste treatment and disposal technologies were developed by asking questions such as:

- What are the potential undesirable consequences of treating and disposing of special wastes? How can they be prevented or mitigated? How effective are the possible preventive/mitigative measures?

- What are the risks to human health and how can they be minimized? What potential impacts (if any) cannot be prevented or mitigated?

- What are the potential impacts on the environment (if any) and how can they be minimized?

- What are the financial costs of treating and disposing of special wastes, including operational controls to minimize health risks and environmental impacts?

These questions were considered in view of the available treatment and disposal technologies, and the following evaluation criteria (shown in order of priority) were developed as a result:

- Maximize protection of worker and community health and safety in the event of an abnormal occurrence (abnormal events).

- Maximize protection of human health and the environment under normal operating conditions (normal events).

- Maximize effectiveness of treatment for different types of wastes and varying waste composition (input flexibility).

- Maximize ability to start and stop treatment as needed (operational flexibility).

- Maximize reliability of process equipment (operational reliability).

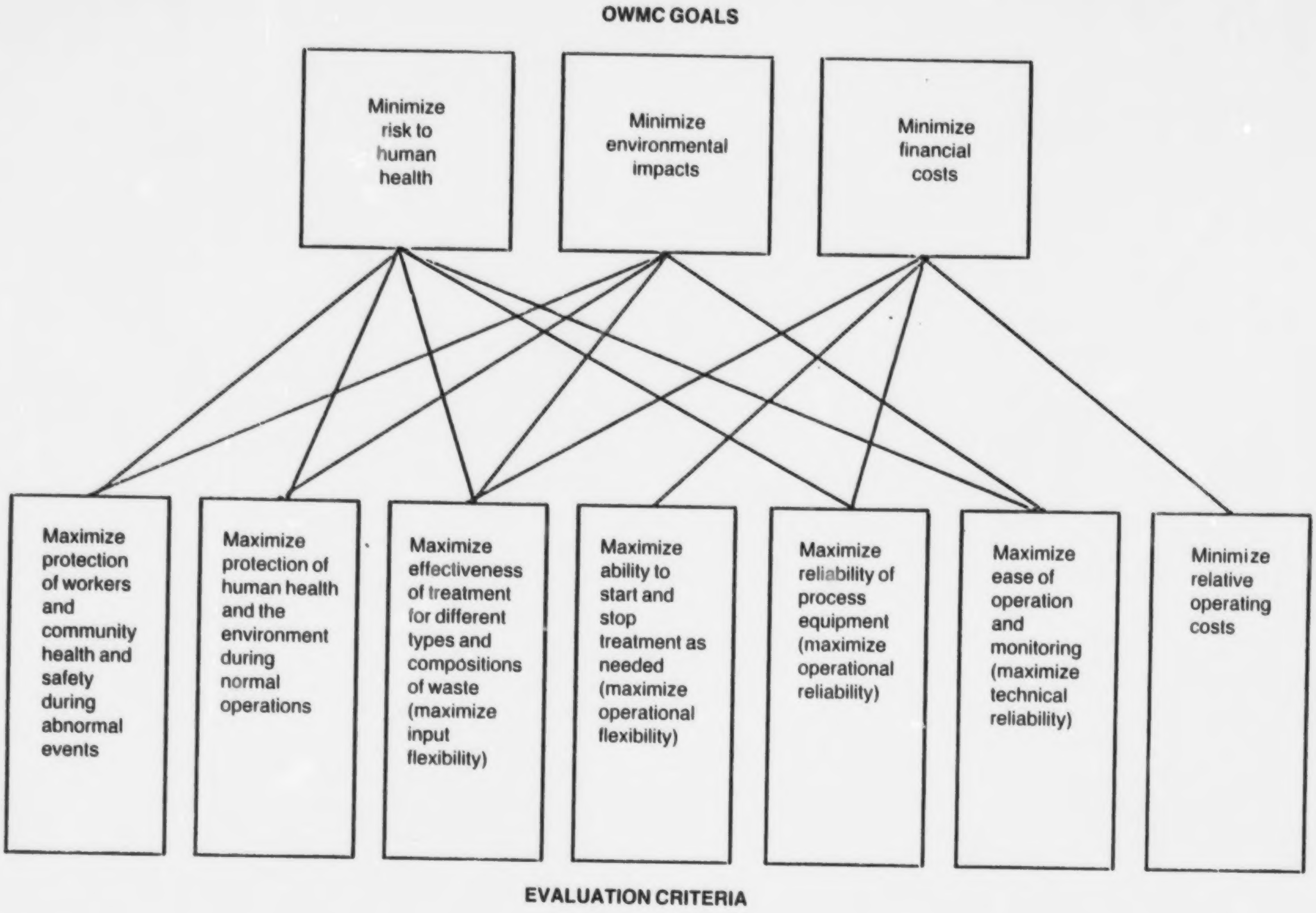
- Maximize ease of operation and monitoring (technical reliability).

- Minimize relative operating cost (cost).

Figure 3.1 shows the relationship of these criteria to OWMC's stated goals. Each goal is addressed by at least four evaluation criteria.

Before the evaluation criteria were applied to the waste/technology combinations, measures and ratings were developed for each, as shown in Table 3.1. The measures describe the criteria more specifically so that the waste/technology combinations can be rated in terms of them as excellent, good or fair. For example, the criterion "Maximize protection of human health and the environment under normal operating conditions (normal events)" has two measures: nature of off-site discharges during normal operation, and type of special protective equipment required during normal operations. Each of these measures can be evaluated for a given waste/technology combination according to the excellent, good and fair ratings presented in Table 3.1.

It is important to remember that all of the waste/technology combinations evaluated herein assign each waste type to proven technologies. The ratings "excellent," "good," and "fair" describe the relative degree to which waste/technology combinations meet the criteria. No waste/technology combination is unacceptable with respect to any of the criteria. Appendix D presents more detailed discussion of the criteria, criteria measures, and ratings.


OWMC GOALS
Minimize risk to human health
Minimize environmental impacts
Minimize financial costs
Maximize protection of workers and community health and safety during abnormal events
Maximize protection of human health and the environment during normal operations
Maximize effectiveness of treatment for different types and compositions of waste (maximize input flexibility)
Maximize ability to start and stop treatment as needed (maximize operational flexibility)
Maximize reliability of process equipment (maximize operational reliability)
Maximize ease of operation and monitoring (maximize technical reliability)
Minimize relative operating costs
EVALUATION CRITERIA

Note: The relationship between OWMC goals and the evaluation criteria is addressed in Appendix D.

FIGURE 3.1 RELATIONSHIP OF EVALUATION CRITERIA TO OWMC GOALS

TABLE 3.1

EVALUATION CRITERIA, MEASURES AND RATINGS

CRITERIA AND MEASURES	RATINGS		
	Excellent	Good	Fair
• Maximize protection of worker and community health and safety in the evnet of an abnormal occurrence (abnormal events)			
- onsite release and consequences	- No worker exposure or no releases into the workplace	- Small on-site releases leading to no irreversible damage	- Potentially serious consequences to worker health and safety
- offsite release and consequences	- No releases beyond the site boundaries	- Small releases beyond the site boundaries leading to no irreversible damage	- Potentially serious consequences to the surrounding community
• Maximize protection of human health and the environment under normal operating conditions (normal events)			
- offsite discharge	- No worker exposure or discharge beyond site boundaries	- Analysis of all emissions and effluents prior to release	- Continuous monitored discharges
- need for personal safety equipment	- No personal protective equipment required to prevent worker exposure	- Worker exposure preventable through use of safety monitors	- Preventable worker exposure, personal protection equipment required
• Maximize effectiveness of treatment for different types of wastes and varying waste composition (input flexibility)			
- number of waste types treatable	- Capable of treating all special wastes	- Capable of treating many types of wastes	- Capable of treating very few types of wastes
- sensitivity to variations in waste composition	- Insensitive to variations in waste composition	- Moderately sensitive to variations in waste composition	- Highly sensitive to variations in waste composition

TABLE 3.1 (continued)

CRITERIA AND MEASURES	RATINGS		
	Excellent	Good	Fair
• Maximize ability to start and stop treatment as needed (operational flexibility)			
- type of operation	- Batch operations	- Semi-continuous operation	- Continuous operation
• Maximize reliability of process equipment (operational reliability)			
- amount of unscheduled downtime	- Less than 5% unscheduled downtime	- Unscheduled downtime of 5-20% equipment (operational reliability)	- More than 20% unscheduled downtime
• Maximize ease of operation and monitoring (technical reliability)			
- ease of operation	- Simple to operate	- Moderately complex to operate	- Complex to operate
- ease of monitoring	- Automatic, continuous monitoring of proven effectiveness and discharge	- Continuous monitoring with operator support	- Periodic, manual monitoring
• Minimize relative capital and operating cost (cost)			
- relative capital and operating cost	- Less than half of intermediate cost	- Intermediate cost	- More than twice intermediate cost

RANKING PROCEDURE

A standard numerical technique known as Conjoint Analysis (8) was used to determine the relative importance of each of the criteria to OWMC and to establish the relative difference between an excellent, good or fair rating for each measure for each of the criteria. The Conjoint Analysis technique is based on the premise that, while individuals or groups often cannot explain the complex decision-making process they use, they do make decisions. In Conjoint Analysis, a population of decision-makers is asked to express preferences among a carefully structured set of hypothetical alternatives. These decisions can then be statistically analyzed to determine the trade-offs that were actually (but implicitly) used in reaching the decision.

For this project, members of the OWMC staff were presented with a set of cards, each card describing a hypothetical technology. The descriptions were taken from the body of Table 3.1 and basically consisted of an entry from either the fair, good or excellent column for each of the criteria measures. The staff members were simply asked to sort the cards on a scale of 1 to 8, with 8 being the most desirable technology (or technologies) and 1 being the least desirable. A standard computer algorithm had been used to systematically develop the set of hypothetical technologies such that, when the cards were placed in order of preference, the relative importance to the staff members of the underlying criteria measures could be quantified.

The results of the Conjoint Analysis are shown in Figure 3.2 and described in detail in Appendix D. Figure 3.2 displays the relative importance (weight) to OWMC of each evaluation criteria. The criterion of greatest importance to OWMC is clearly protection of worker and community health and safety in case of accident or other abnormal event. The criterion of least importance is cost. The sum of the criteria weights is 100%.

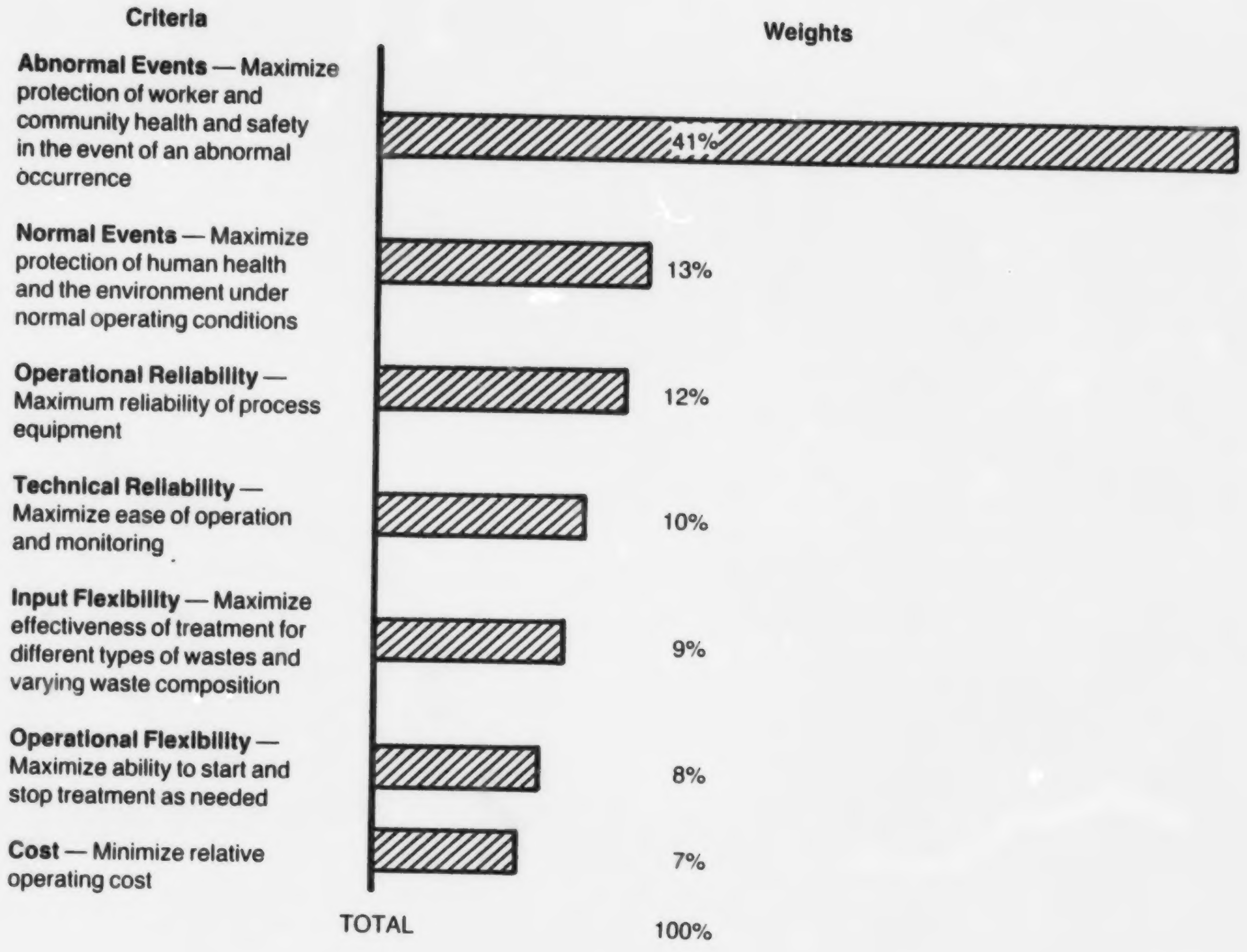


FIGURE 3.2 RELATIVE IMPORTANCE OF CRITERIA TO OWMC

DESCRIPTION OF WASTE/TECHNOLOGY COMBINATIONS

This section describes, according to the evaluation criteria, the proven technologies identified in Chapter 2. The information presented was used in ranking the waste/technology combinations. Results of the ranking are discussed in the following section. Additional information on the technologies is available in Proctor & Redfern(1) and in Appendix C.

The cost information presented represents costs for treating the typical waste streams described by the UCD categories. The costs in the "Expected Cost" column are calculated for systems sized to treat the annual quantity of waste which may be received by OWMC, as defined in Appendix B. "Economic Costs" are also given to indicate the operating cost for the amount of waste for which the technology is typically used. Costs cover all incremental operating costs including labor, materials, and power, but do not account for capital recovery charges (principal repayments or interest), return on investment, depreciation, or income taxes. All costs are in Canadian dollars, December 1985.

BIOLOGICAL TECHNOLOGIES (9)-(21)

Features that characterize generic biological technologies include: oxygen-supported or anaerobic digestion, dispersed or immobilized microorganisms, and liquid phase or non-liquid phase microbial growth.(1) The characteristics of the nine proven biological technologies previously listed in Table 2.1 are:

- Activated Sludge--aerobic, dispersed media, liquid phase.
- Activated Sludge Using Pure Oxygen--aerobic, dispersed media, liquid phase.
- Anaerobic Digestion--anaerobic, dispersed media, liquid phase.

- Fluidized-Bed Contactor--aerobic, immobilized microorganisms, liquid phase.

- Land Treatment--aerobic, fixed media, solid phase.

- Activated Sludge/Powdered Activated Carbon Treatment--enhanced aerobic, dispersed media, liquid phase.

- Rotating Biological Contactor--aerobic, immobilized microorganisms, liquid phase.

- Trickling Filter--aerobic, immobilized microorganisms, liquid phase.

- Waste Stabilization Pond--aerobic/anaerobic, dispersed media, liquid phase.

Each technology can be undertaken either in tanks (indoors) or in ponds (outdoors), except for waste stabilization ponds and land treatment, which must occur outdoors. When there is a choice, tank technologies pose less risk to the environment from spills and containment system failure, are easier to maintain at optimal temperatures year round, and are more easily covered and vented to ensure that volatile organics are not released in the atmosphere. For treatment of quantities of wastes greater than about 10,000 tonnes/year, space requirements and economic considerations tend to favour lined, in-ground ponds over tank systems.

Treatable Wastes

Aqueous solutions containing less than 1% of organics and low concentrations of metals and salts are generally treatable by aerobic, liquid phase biological technologies. Anaerobic technologies can treat aqueous solutions with slightly higher concentrations of organics, provided that they are not highly chlorinated. Activated sludge/powdered activated carbon treatment is effective for a wider range of waste categories and compositions than either of the previous two processes, since biological digestion of short chain hydrocarbons is combined with carbon adsorption of organics that are less readily biodegradable. Land treatment is a proven technology for petroleum refining and leather tanning wastes.(16),(21)

Discharges

The total discharge streams from liquid phase biological systems are approximately equal in volume to the incoming waste stream, but are up to 75% lower in chemical oxygen demand (COD)*. This reflects the ability of the technologies to degrade organics in the input wastes. The liquid effluent stream is separated from a slurry discharge (biological solid residue) by sedimentation in the biological reactor. After filtration, the effluent stream is released to the environment as a "batch" discharge, meaning that the stream is collected and analyzed prior to release; if necessary, the effluent is treated further to meet applicable Ontario standards. The spent biomass slurry stream may contain heavy metals and non-degraded organics, and is further treated by incineration or wet air oxidation. Biological technologies also produce an off-gas, which may contain entrained or volatile organic materials. Off-gasses from biological reactors (except waste stabilization ponds and land treatment units) can be collected, cleaned or incinerated, thereby preventing releases to air during normal operations.

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* COD is the measure of the amount of oxygen required to oxidize the waste stream as a weight percentage of the inlet stream.

Normal Operating Characteristics

All of the biological technologies are similar in their operation.

A primary consideration that affects the choice of biological treatment systems for in-plant use is their sensitivity to changes in both waste composition and operating conditions. Shock loading of biological systems or feeding of highly-halogenated materials will effectively stop the microbial digestion technology. Also, temperature fluctuations must be avoided to optimize microbial growth rates. Combined activated sludge/powdered activated carbon is less sensitive to minor constituents in the waste stream and can receive a broader range of wastes.

The waste stabilization pond and the anaerobic digestor are the simplest systems because they require no aeration equipment. The rotating biological contactor, fluidized bed contactor and trickling filter are more complex because of the equipment used to hold the immobilized microbial media and provide oxygen to the system.

Waste stabilization ponds and land treatment can be operated in the batch mode. The other biological technologies must be fed waste and nutrients on a nearly continuous basis to maintain an active colony of microorganisms. The aerobic technologies also require an adequate supply of oxygen to optimize microbial growth and prevent odours. All technologies are expected to operate with low to moderate unscheduled downtime, if processing parameters are well-controlled and operators are well trained. Land treatment is the only technology that requires additional special personnel protective equipment; a respirator and protective clothing should be worn during land application of volatile organic wastes.

Abnormal Events

Biological technologies carried out in above-ground tank systems are unlikely to have a major impact on the environment, even in the event of accidents or incidents. First, the systems are small in volume (30-40 cubic metres). Second, the treatable wastes are of relatively low toxicity. Third, spills caused by hardware failures can be captured in the spill containment system and sent to further treatment as required. A waste stabilization pond may have releases to the environment if the pond liner fails or if the pond overflows under flood conditions in excess of design standards. In the case of a pond liner failure, groundwater contamination should be detected by monitoring wells so that corrective action can be taken before contaminants reach the site boundary. Abnormal releases to the environment from properly designed and operated land treatment systems should be limited to flood conditions that cause the capacity of surface runoff control systems to be exceeded. Waste stabilization ponds and land treatment are less desirable than the other biological technologies by this criterion because they are in-ground rather than tank technologies.

Operating Costs

Technology	Expected Cost ($/tonne)	Economic Cost ($/tonne)
Activated Sludge	15	15
Anaerobic Digestion	15	15
Fluidized Bed Contactor	15	15
Land Treatment	30	6
Activated Sludge/Powdered Activated Carbon	20	20
Rotating Biological Contactor	15	15
Trickling Filter	15	15
Waste Stabilization Ponds	35	8

PHYSICAL TECHNOLOGIES (22)-(37)

Many aqueous wastes, emulsions, slurries and sludges can be separated or reduced in volume by physical processing. Typically, physical technologies concentrate the more hazardous portion of the waste into a smaller volume for further treatment or disposal, producing an effluent stream that is less hazardous. As an example, removing heavy metal cake from a slurry by filtration or centrifugation concentrates the heavy metal particles in the cake fraction and creates an effluent fraction with little or no heavy metal content. In some cases the "clean" stream will be further detoxified prior to release to a municipal sewer or receiving water body in conformance with regulations.(38)

The proven technologies for volume reduction or physical separation of waste stream components are:

- Air Stripping
- Carbon Adsorption
- Centrifugation
- Dissolved Air Flotation
- Electrodialysis
- Emulsion Breaking
- Evaporation
- Filtration
- Flocculation/Sedimentation
- Resin Adsorption
- Reverse Osmosis
- Solvent Extraction
- Steam Stripping
- Ultrafiltration

Treatable Wastes

Wastes that are treatable by physical processing include aqueous organic solutions, slurries and sludges with less than about 40% total solids, oil/water emulsions, salt solutions, and solutions with suspended heavy metal precipitates. Solids and sludges with greater than 40% total solids may be dispersed in water if they would benefit from physical treatment.

Discharges

All physical treatment technologies yield one or more streams with concentrated hazardous constituents that require further treatment or disposal, and other streams that may be acceptable for release to the environment or that may also require further treatment. Air stripping, carbon adsorption, electrodialysis, evaporation, resin adsorption, reverse osmosis, steam stripping and ultrafiltration usually yield a discharge stream that can be released. Centrifugation, emulsion breaking, dissolved air flotation, filtration, flocculation and sedimentation, and solvent extraction normally have a discharge stream that must be treated further before release.

Normal Operating Characteristics

Physical technologies can generally be carried out in closed systems so that workers are not exposed to the wastes. Protective clothing may be required if solids are removed manually from solid/liquid separation systems such as centrifugation, dissolved air flotation, filtration, flocculation, and sedimentation.

The physical separation technologies are normally batch operations. They are typically simple to moderately complex, depending on the number of operations involved in each technology. Filtration and centrifugation are simple since they use only a single piece of technology equipment. Solvent extraction and steam stripping are more complex, with three or four major processing components.

Generally, physical technologies are relatively insensitive to the composition of the waste streams. Exceptions are the membrane purification technologies--reverse osmosis, ultrafiltration and electrodialysis--which are prone to fouling of the membranes by several possible waste stream components, such as oils and greases, solvents, and some metals including iron. Such fouling problems can also result in more extensive unscheduled downtime for membrane purification technologies.

Abnormal Events

All physical technologies have comparable risk due to abnormal events. With all physical technologies, spills may occur during loading and unloading or due to tank ruptures. If a spill occurs, the waste released can be collected in the spill containment system and sent to treatment as required, thus preventing human and environmental exposure. If the spilled wastes contain high concentrations of volatile organics, there may be air emissions to the workplace for a short period before the spill is cleaned up. Fire or explosion, in addition, is possible with solvent extraction.

Operating Costs

Technology	Expected Cost ($/tonne)	Economic Cost ($/tonne)
Air Stripping	3	3
Carbon Adsorption	65	65
Centrifugation	2	2
Dissolved Air Flotation	20	7
Electrodialysis	2	2
Emulsion Breaking	20	20
Evaporation	20	20
Filtration	2	2
Flocculation/Sedimentation	40	5
Resin Adsorption	85	60
Reverse Osmosis	1	1
Solvent Extraction	75	75
Steam Stripping	10	10
Ultrafiltration	2	2

CHEMICAL TECHNOLOGIES (39-50)

Some waste streams must be chemically treated to convert the primary hazardous constituents to less hazardous forms. The proven chemical treatment technologies are:

- Chemical Reduction
- Chemical Oxidation
- Dehalogenation
- Ion Exchange
- Neutralization
- Precipitation
- Wet Air Oxidation

Treatable Wastes

Each chemical technology normally treats only a narrow range of wastes. Neutralization can be used to convert acidic and alkaline wastes to neutral salts. Wet air oxidation can be used to convert organic wastes to less hazardous forms. The other treatment technologies are highly specific to actual waste composition.

Discharges

Wet air oxidation is the only chemical technology with a continuous release to the environment (air emission); all other discharge streams can be analyzed prior to release. In most cases further treatment is needed before release.

Normal Operating Characteristics

Each chemical technology has specific environmental, health, and safety characteristics inherent to the type of wastes, technologies, and reagents used. Some technologies require special personnel protective equipment, such as respirators when working with cyanide wastes.

Neutralization and precipitation are simple to operate in comparison with other technologies. The equipment required is a stirred tank, with cooling capability and various feed and discharge mechanisms. Ion exchange is a somewhat more complex technology that includes a regeneration system. The other technologies are even more complex because of the equipment and controls required to accomplish the reactions safely and effectively.

All chemical technologies tend to be sensitive to changes in operating conditions and feed composition. This is particularly true for technologies such as dehalogenation or chemical oxidation, where minor waste components may "poison" the chemical reaction or cause unwanted side reactions that create hazards or unnecessary consumption of expensive reagents. These problems can be controlled through careful analysis of input waste.

All three chemical technologies, except for wet air oxidation, can be operated in batch mode. That is, they can be started and stopped as needed, and the equipment can be emptied between uses.

All chemical technologies, except wet air oxidation, are expected to have minimal unscheduled downtime. Wet air oxidation may require more unscheduled maintenance (e.g., for pumps, compressors, and seals) since it is a more complex technology and operates under pressure.

Abnormal Events

Possible accidents include spills, equipment failure, pressure releases, and explosions. With several chemical technologies, there is a chance of harm to the operators and release to the environment. For instance, the sodium dehalogenation technology for PCB-contaminated wastes can release hydrogen under some conditions. Wet air oxidation units, which are operated at more than twenty times atmospheric pressure, could experience pressure failures.

Operating Costs

Technology	Expected Cost ($/tonne)	Economic Cost ($/tonne)
Chemical Reduction	35	35
Chemical Oxidation	35	35
Dehalogenation	1,000	1,000
Ion Exchange	5	5
Neutralization	10	10
Precipitation	10	10
Wet Air Oxidation	15	15

THERMAL TECHNOLOGIES (51)-(59)

Thermal technologies destroy organic wastes by oxidizing them at temperatures of up to 1,400°C. The proven thermal technologies are:

- Fluidized Bed Incineration.
- Liquid Injection Incineration.
- Multiple-hearth Incineration.
- Pyrolysis.
- Rotary Kiln Incineration.

Cement kilns, which represent a proven treatment technology for special wastes with limited solids and chlorine content, are not included in the above list even though several owners and operators of existing cement kilns in Canada have found it economic to burn wastes for their energy. Wastes are thermally destroyed by the technology, as they are by incineration, but this is an auxiliary function to production of cement. Cement kilns, lime kilns, and aggregate kilns were eliminated based on the premise that OWMC must operate a treatment and disposal facility, rather than a manufacturing facility, and that this capacity presently exists in Ontario in the private sector.

Multiple hearths have been used for many years, to burn wastewater treatment sludges and certain homogeneous sludges that are generated and burned on industrial sites. However, municipal wastewater treatment sludges will not be accepted at the OWMC facility, and OWMC is not likely to receive sufficient quantities of homogeneous sludges to support installation of a multiple hearth. Therefore, multiple hearth incineration was eliminated from the list of viable technologies.

Treatable Wastes

All organic wastes are treatable by thermal destruction. These wastes include solutions, slurries, sludges, and solids and can range from 100% organic to varying percentages of organics mixed with water or inorganics. Examples of incinerable wastes are contaminated solvents such as methyl ethyl ketone, highly-chlorinated hydrocarbons such as PCBs, tars and still bottoms.

The rotary kiln is capable of treating all the organic wastes, including large solid materials such as drums, as well as various forms of wet materials, such as gunky wastes. The fluidized bed incinerator can treat all wastes except those that are significantly chlorinated or fluorinated. Also, solids must be shredded before they are fed to fluidized beds. Liquid injection can only be used for non-viscous fluid wastes that can be atomized and burned in suspension. Pyrolysis units have broader applicability than liquid injection incinerators, but cannot treat as wide a range of organic wastes as rotary kilns or fluidized beds.

Discharges

There are three significant discharge streams from thermal technologies. Air emissions are created and released continuously via the stack following adequate flue gas treatment. The second discharge stream is solid ash and slag residue (except in the case of liquid injection incineration, where there is typically little or no ash). The third, is a liquid or solid salt waste formed in the flue gas treatment system. (This analysis assumes "dry" flue gas scrubbing, where the scrubbing solution is evaporated to form a dry salt residue for disposal, because of OWMC's commitment to minimize effluent.)

The air emissions represent the primary concern from an environmental viewpoint. These unavoidable emissions may cause some environmental harm during normal operations, even though at least 99.99% of the organic constituents of the wastes are destroyed, and state-of-the-art flue gas treatment systems can be fitted to all types of incinerators. The flue gas treatment system is designed to ensure adequate contaminant removal, and the stack to ensure adequate dispersion of the emissions before they reach ground level. Studies done in both the U.S. and Canada have shown that the increase in risk due to the release of such small quantities of toxic organic materials is too small to measure by epidemiologic studies on the exposed population.(58),(59) Furthermore, even though the continuous air emissions from incinerators are generally considered undesirable, high temperature thermal destruction is the only proven technology for many organic and biomedical wastes.

Normal Operating Characteristics

Thermal technologies raise several health and safety concerns. Some of these concerns relate to the waste stream itself. Opening of drums and feeding of sludges and solids to the incinerator present a greater risk to the workers, for example, than does the pumping of liquids from an enclosed tank system. These risks, although associated with processing by thermal destruction, are actually common to any treatment technology which receives the same type of wastes.

In terms of operation, the thermal technologies are all similar. They function more efficiently and more reliably when operating continuously. Certain technologies such as rotary kiln incineration must be operated virtually continuously because of the long times required to start and stop the equipment and the accelerated deterioration of the refractory lining caused by frequent heating and cooling cycles. Liquid injection incineration can be operated intermittently.

All thermal technologies are complex, involving several simultaneous or sequential operations to ensure adequate combustion and flue gas cleanup. Automatic controllers are used to monitor and control key parameters, and periodic stack sampling is conducted to ensure that adequate destruction and removal efficiency and burnout are maintained. Due to the complexity of these technologies, a substantial amount of unscheduled downtime is typical of all technologies except liquid injection.

Thermal technologies are relatively insensitive to changes in waste composition. The high temperatures (from 1400°C for the rotary kiln, to 800°C for the fluidized bed), high oxygen content (approximately 3%-10% excess oxygen in the flue gas), and long residence times (one or more seconds) ensure adequate burnout for essentially all organic materials. Wastes and auxiliary fuels must be introduced to the system so that the heat content is neither so low that operating temperatures drop below minimum requirements, or so high that excessive heating of the equipment occurs.

Abnormal Events

All incineration technologies score poorly regarding the risk of abnormal events. Under abnormal conditions, thermal processing can lead to significant releases and threat to workers within the plant as well as to the external environment. Explosion and fires represent one extreme. At the other extreme are incremental air emissions due to excursions outside of the specified range of incinerator operating parameters or breakdown of air pollution control equipment. These last two would generally be detected by the automated incinerator controls, and action could be taken within minutes. Incidents such as air inversions could expose off-site populations to risks due to poor dispersion of the stack plume.

Operating Costs

Technology	Expected Cost ($/tonne)	Economic Cost ($/tonne)
Fluidized Bed Incineration	95	95
Liquid Injection Incineration	90	90
Pyrolysis	95	95
Rotary Kiln Incineration	105	105

STABILIZATION/SOLIDIFICATION TECHNOLOGIES (60)-(62)

Stabilization and solidification are used to reduce the hazard of liquids, sludges and solids by incorporating them into a solid matrix. This reduces their leachability. When the stabilized wastes are placed in an engineered landfill, the potential for groundwater contamination is reduced because the quantity of leachate generated is substantially reduced and the leachate which is generated will contain less dissolved waste.

Lime, cement, pozzolans and silicates are normally used for stabilization and solidification. This approach is fundamentally different from one where free liquids are absorbed in a substance like vermiculite. In the latter case, absorbed liquids can be released easily by washing whereas with stabilized solids, the wastes become chemically bound within the solid-state matrix.

Treatable Wastes

Wastes and residuals that are treatable by stabilization and solidification include aqueous liquids with inorganic hazardous compounds, inorganic sludges (limes and metal sludges), inorganic solids and brines. Organic wastes are not normally treatable by stabilization or solidification.

Discharges

The only discharge stream is the stabilized waste. This stream is sent final disposal.

Normal Operating Characteristics

The equipment used in stabilization and solidification is generally a closed mixer (e.g., pug mill) so that workers are not exposed to the waste. Clean-out of this equipment is by washing and does not normally require entry into the equipment.

The technology can be batch or continuous, requiring clean-out upon shutdown to ensure easy removal of all solids from the mixer. Technology operation is simple, requiring only metering of waste and stabilizing agent to the mixer. Within bounds, the technology is not too sensitive to minor constituents. Unscheduled downtime should be low.

Abnormal Events

There is little potential for spills, explosions, fires, or toxic emissions from these technologies.

Operating Costs

The operating cost of stabilization technology is approximately $35 per tonne of sludge. Costs may increase for either solids or liquids.

DISPOSAL TECHNOLOGIES (63)-(65)

The proven disposal options are:

- Geologic isolation
- Deep well injection
- Engineered landfill
- Warehouse storage

In keeping with OWMC policy, the disposal technologies of geologic isolation, engineered landfill, and warehouse storage are applicable to solidified waste only; deepwell injection could be used for the effluent from treatment of aqueous wastes.

Treatable Wastes

No incoming wastes are treatable directly by the disposal technologies. OWMC has stated that special wastes will undergo treatment before disposal and at least one other treatment technology is applicable to each UCD category. Only treated and solidified wastes and residues are disposed of. Inorganic laboratory waste in lab packs (UCD 513), which is often landfilled, will be analyzed and treated in accordance with the characteristics of the waste (assuming a procedure is developed which does not expose operators to unacceptable occupational risk). Deepwell injection is a proven technology only for liquid wastes.

Discharges

No air emissions are expected from any of the disposal options, since disposal is limited to treated wastes. Geologic isolation, deepwell injection and warehouse storage are intended to have no aqueous discharges. The liquid discharge from engineered landfill is leachate, formed from percolation of rainfall or snowmelt through the buried waste mass. The leachate is collected for further treatment as necessary.

Normal Operating Characteristics

Disposal technologies may require the use of respirators to protect workers at the site against direct inhalation of dust. This is particularly true for landfill operations, where solidified wastes and sludges may be disposed of in bulk (i.e. non-containerized). All the disposal technologies, except deep well injection, may require special protective clothing or environmental enclosures to prevent worker exposure during waste handling, even though the waste has already been detoxified or stabilized as much as possible.

As operations, all of the disposal technologies are moderately complex, batch or semi-continuous (in the case of deep well injection), and manually controlled by the operator. With the exception of deep well injection, they are relatively insensitive to variations in waste composition. Unscheduled downtime should be moderate for deep well injection and low for other technologies.

Abnormal Events

In the operation of disposal facilities, there are two kinds of abnormal events that could potentially affect human health or the environment: (1) mechanical problems such as wellhead failures in deep well injection or ventilation failures in cavern storage, and (2) natural events, such as floods, which can carry waste from a land disposal site. In either case, the major concern is failure of the containment system. The effects are minimized by proper siting in areas that are not prone to flooding.

Geologic isolation of waste in unique formations in the earth such as salt mines (which have been isolated from adjacent geological features for thousands of years already) should in principle preclude unintentional release, particularly when only used for solid, treated residuals from the OWMC facility. However, geologic isolation of special wastes has only been used at one site, in West Germany, for about ten years. Its long term performance is therefore unknown.

Engineered landfills have had a history of liner failures. If failures do occur, they must be located and corrected to mitigate or reverse the damage to the environment. OWMC will dispose of only solid treated wastes in engineered landfill in order to minimize both the potential for leachate generation and the toxicity of any leachate formed. As a second line of defense, the engineered landfill will be underlain by a natural clay layer or other impervious boundary.

Groundwater contamination from deep well injection can occur if the well is improperly constructed or improperly closed, allowing contaminants to enter aquifers above the injection zone. In addition, failure of the well head or pump may expose on-site personnel to the waste being injected.

Warehouse storage of bulk, solidified residuals poses little risk due to abnormal events, provided the warehouse is well-maintained to protect the waste from precipitation and flooding. Flooding in excess of the design flood could result in off-site transport of the deposited materials.

Operating Costs

Technology	Expected Cost* ($/tonne)	Economic Cost* ($/tonne)
Deep Well Injection	15	10
Geologic Isolation	175	175
Engineered Landfill	75	75
Warehouse Storage	210	210

*During active life; exludes post-closure care/perpetual maintenance.

RANKING OF WASTE/TECHNOLOGY COMBINATIONS

The numerical weights and measures derived from the Conjoint Analysis were combined, as described in Appendix D, to calculate a numerical score for each waste/technology combination. Since the scores obtained were relative, a simple change of scale allowed the raw scores to be converted to positive numbers relative to a maximum score of 100 ("excellent" for every criterion). The scores were then expressed as letter grades (Table 3.2) corresponding to the numerical scores shown in Appendix D.

The highest ranking (A) technologies involve relatively simple physical separations (flocculation/sedimentation, centrifugation, electrodialysis, filtration, reverse osmosis, and solidification) and chemical reactions (neutralization, ion exchange and precipitation) that generally can be carried out at room temperature and pressure in closed systems.

The lowest ranking (C) technologies are thermal and chemical destruction technologies (incineration, pyrolysis, wet air oxidation, chemical oxidation and dehalogenation), land-based biological technologies (land treatment and waste stabilization ponds), and solvent extraction. Thermal and chemical technologies and solvent extraction receive low rankings due to the potential for release of constituents with a relatively high degree of hazard. Thermal technologies can be designed and operated to destroy at least 99.99% of the organic chemicals in a waste feed, but the small unburned fraction (less than .01% of the feed) is emitted continuously under normal operations. There is also a potential for adverse consequences due to abnormal events such as fires, explosions, or atmospheric inversions. Chemical oxidation, as applied to cyanide wastes, is ranked relatively low due to the possibility for accidental release of hydrogen cyanide gas. Active sodium dehalogenation is ranked relatively low because the reagent can react explosively with moisture. Land treatment and waste stabilization ponds are ranked relatively low, since wastes could be carried off-site during a flood in excess of the design flood. The other biological, physical, chemical, and disposal technologies are intermediate (B) in rank.

Table 3.3 lists the highest ranking technology(ies) applicable to each UCD Category. Nineteen of the forty-three proven technologies are included in Table 3.3. Overall, 38 (46%) of the UCD categories

TABLE 3.2
TECHNOLOGY SCORES

Technology	Ranking*
BIOLOGICAL	
activated sludge	B
activated sludge/ powdered activated carbon	B
rotating biol contactor	B
anaerobic digestion	B-
fluidized bed contactor	B-
trickling filter	B-
land treatment	C
waste stabilization pond	C
PHYSICAL	
centrifugation	A
flocculation/sedimentation	A-
electrodialysis	A-
filtration	A-
reverse osmosis	A-
solidification	A-
air stripping	B
carbon adsorption	B
dissolved air flotation	B
emulsion breaking	B
evaporation	B
resin adsorption	B
steam stripping	B
ultrafiltration	B
solvent extraction	C+
CHEMICAL	
ion exchange	A
neutralization	A
precipitation	A
chemical reduction	B
chemical oxidation	C
dehalogenation	C
wet air oxidation	C
THERMAL	
fluidized bed incineration	C
liquid injection incineration	C
pyrolysis	C
rotary kiln incineration	C
DISPOSAL	
geologic isolation	B+
deep well injection	B
secure landfill	B
warehouse storage	B

* Based on scoring in Appendix D

TABLE 3.3

HIGHEST RANKING WASTE/TECHNOLOGY COMBINATIONS

UCD CATEGORY	DESCRIPTION	HIGHEST RANKING TECHNOLOGIES (LETTER GRADE)
• ORGANIC WASTES		
211	Halogenated Solvents with Heavy Metals	Centrifugation (A)
212	Halogenated Solvents with Other Metals	Centrifugation (A)
213	Halogenated Solvents	Rotary Kiln, Fluidized Bed, Liquid Injection (C)
214	Non-Halogenated Solvents with Heavy Metals	Centrifugation (A)
215	Non-Halogenated Solvents with Other Metals	Centrifugation (A)
216	Non-Halogenated Solvents	Rotary Kiln, Fluidized Bed, Liquid Injection (C)
217	Unspecified Solvents	Rotary Kiln, Fluidized Bed, Liquid Injection (C)
221	Organic Liquids with Metals and Halogens	Centrifugation (A)
222	Organic Liquids with Halogens Only	Rotary Kiln, Fluidized Bed, Liquid Injection (C)
223	Organic Liquids with Metals Only	Rotary Kiln, Fluidized Bed, Liquid Injection (C)
224	Other Organic Liquids	Rotary Kiln, Fluidized Bed, Liquid Injection (C)
225	Aqueous Solution with non-Halogenated Residues Less Than 10%	Activated Sludge/Powdered Activated Carbon (B)
226	Aqueous Solutions with Halogenated Residues Less Than 10%	Activated Sludge/Powdered Activated Carbon (B)
227	Aqueous Solution with Non-Halogenated Organic Residue Greater Than 10%	Solvent Extraction (C+)

TABLE 3.3 (continued)
(page 2 of 6)

UCD CATEGORY	DESCRIPTION	HIGHEST RANKING TECHNOLOGIES (LETTER GRADE)
228	Aqueous Solution with Halogenated Organic Residue Greater than 10%	Solvent Extration (C+)
241	Pesticides and Wastes	Rotary Kiln, Fluidized Bed (C)
242	PCB Oils and High Strength (over 500 ppm) Liquids	Rotary Kiln, Fluidized Bed, Liquid Injection, Dehalogenation (C)
243	Pharmaceuticals and Waste	Rotary Kiln, Fluidized Bed (C)
244	Photochemicals and Waste	Rotary Kiln, Fludized Bed (C)
245	Off-Spec or Aged Organics	Rotary Kiln, Fluidized Bed (C)
247	Halogenated Still Bottoms	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
248	Non-Halogenated Still Bottoms	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
252	Solid or Sludge Tannery Wastes	Rotary Kiln, Fluidized Bed, Pyrolysis, Wet Air Oxidation, Land Application (C)
254	Adhesives or Glue	Rotary Kiln, Fluidized Bed, Wet Air Oxidation (C)
257	Phenolic Wastes	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
258	Waste Tar and Residues	Rotary Kiln, Fluidized Bed (C)
261	Polymeric Resin	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
262	Latex Wastes	Flocculation/Sedimentation (A-)

TABLE 3.3 (continued)
(page 3 of 6)

UCD CATEGORY	DESCRIPTION	HIGHEST RANKING TECHNOLOGIES (LETTER GRADE)
263	Other Polymeric Wastes	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
264	Thermoset Wastes	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
281	Waste Oil and Mixed Oil	Emulsion Breaking (B)
282	Oily Tank Bottoms	Emulsion Breaking (B)
283	Oily Mud, Sediment and Water	Centrifugation (A)
284	Oily Acidic Solids	Rotary Kiln, Fluidized Bed, Pyrolysis, Land Application (C)
285	Oily Alkaline Solids	Rotary Kiln, Fluidized Bed, Pyrolysis, Land Application (C)
286	Oil/Water Separator Sludge	Rotary Kiln, Fluidized Bed, Pyrolysis, Land Application (C)
288	Oily Wastes with Heavy Metal Contaminants	Centrifugation (A)
289	Oily Wastes with Water	Emulsion Breaking (B)
416	Ink Sludge	Rotary Kiln, Fluidized Bed (C)
446	Degreasing Sludge	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
447	Tetraethyl Lead Sludge	Rotary Kiln, Fluidized Bed, Pyrolysis, Wet Air Oxidation (C)
454	Paint Sludge (organic)	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
455	Paint Sludge without Heavy Metals (organic)	Rotary Kiln, Fluidized Bed, Pyrolysis (C)

TABLE 3.3 (continued)
(page 4 of 6)

UCD CATEGORY	DESCRIPTION	HIGHEST RANKING TECHNOLOGIES (LETTER GRADE)
512	Spill Cleanup	Rotary Kiln (C)
513	Laboratory Waste Chemicals	Rotary Kiln (C)
521	Spent Cartridge Filters	Rotary Kiln (C)
523	Tank Bottom Sediments	Centrifugation (A)
528	Pathogenic Wastes	Rotary Kiln (C)
531	Contaminated Rags	Rotary Kiln, Fluidized Bed, Pyrolysis (C)
532	Equipment and/or Containers Contaminated with Pesticides	Rotary Kiln (C)
• INORGANIC AQUEOUS WASTES		
111	Acidic Solution with Heavy Metals	Precipitation, Ion Exchange (A)
112	Acidic Solution with Other Metals and Non-Metals	Precipitation (A)
113	Other Acidic Solutions	Neutralization (A)
121	Alkaline Solution with Heavy Metals	Precipitation, Ion Exchange (A)
122	Alkaline Solutions with Heavy Metals	Precipitation (A)
123	Other Alkaline Solutions	Neutralization (A)
131	Spent Etchant/Plating Solutions, Acid	Precipitation (A)
132	Spent Etchant/Plating Solution, Alkaline	Precipitation (A)
133	Spent Pickle Liquor from Ferrous and Non Ferrous Metals	Precipitation (A)

TABLE 3.3 (continued)
(page 5 of 6)

UCD CATEGORY	DESCRIPTION	HIGHEST RANKING TECHNOLOGIES (LETTER GRADE)
141	Aqueous Solutions with Other Metals	Centrifugation, Precipitation, Ion Exchange (A)
142	Aqueous Solutions with Other Metals	Centrifugation, Precipitation, Ion Exchange (A)
143	Aqueous Solutions with Reactive Anions	Chemical Reduction (B)
145	Brine	Centrifugation (A)
146	Solution Containing Cyanide	Chemical Oxidation (C)
147	Solution Containing Sulfides	Chemical Oxidation (C)
251	Tannery Wastes	Centrifugation (A)
513	Laboratory Waste Chemicals	As appropriate
• INORGANIC SOLIDS AND SLUDGES		
151	Inorganic Solids	Solidification (A-)
152	Inorganic Solid Chemicals	Solidification (A-)
165	Spent Catalyst	Solidification (A-)
167	Other Inorganic Waste	Solidification (A-)
417	Alum and Gypsum Sludges	Centrifugation (A)
431	Heavy Metal Sludge	Centrifugation (A)
433	Other Metal Sludges	Centrifugation (A)
441	Lime Sludges	Centrifugation (A)
443	Sulphur Sludge	Centrifugation (A)
444	Cyanide Bearing Sludge	Solidification (A-)

TABLE 3.3 (continued)
(page 6 of 6)

UCD CATEGORY	DESCRIPTION	HIGHEST RANKING TECHNOLOGIES (LETTER GRADE)
445	Plating or Metal Finishing Sludge	Centrifugation (A)
454	Paint Sludge (inorganic)	Centrifugation (A)
455	Paint Sludge without Heavy Metals (inorganic)	Centrifugation (A)
509*	Gas Cylinders or Containers	Geologic Isolation (B+)
518	Dust Collector Wastes	Solidification (A-)

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*Not accepted by OWMC.

are treatable by technologies which received a letter grade of A, and 36 (44%) are only treatable by technologies which received a C. There are only eight UCD categories for which the highest technology grade was a B (activated sludge/powdered activated carbon, emulsion breaking, and chemical reduction). Nearly 70% of the organic wastes are treatable only by C technologies (incineration, wet air oxidation, land application, and solvent extraction). In contrast, nearly all (84%) of the inorganic wastes are treatable by A technologies.

Chapter 4 discuss how this ranking of waste/technology combinations was used in developing system options.

CHAPTER 4

DEVELOPMENT AND EVALUATION OF SYSTEM OPTIONS

OWMC defines "systems" as alternative groupings of preferred technologies able to perform complete treatment and/or disposal tasks. Each system option described in this chapter combines modules of proven technologies, which together are capable of treating all types of wastes that may be received by OWMC. Four system options were developed by Arthur D. Little based on the preceding evaluation of waste/technology combinations. The first system option (System 1) involves sending waste to the highest ranking technology capable of treating that waste (see Table 3.3). Two alternative system options (Systems 2 and 3) represent modifications and improvements to System 1 based on OWMC's stated purpose of minimizing risk to human health, environmental impacts, and financial costs to OWMC and the people of Ontario. A fourth system option (System 4) was developed based on conventional European practice. All system options were then evaluated with respect to the technology evaluation criteria and the overall features of each system.

The principal findings presented in this chapter are:

- Overall, there are thousands of system options possible for treatment and disposal of all waste types expected to be received by OWMC.

- All systems are made up of a set of treatment technologies that treats primarily organics and another that treats primarily the inorganics.

- For optimized organic treatment, all organics are incinerated in the rotary kiln except for aqueous streams with less than 10% organics (UCD 225 and 226), which are treated by activated sludge/powdered activated carbon, and oil/water emulsions which may contain up to 95% water (UCD 281, 282, 283 and 289) that are treated by emulsion breaking. By treating these organic streams separately, approximately 40,000 tonnes/year of air emissions (10% of the total) are avoided.

- Inorganic treatment consisting of five technologies (neutralization, precipitation, chemical oxidation, chemical reduction and solidification) best meets OWMC's objectives by optimizing the competing means of residual removal from the plant by air emissions, liquid effluents and land disposal.

PROCEDURE FOR DEVELOPING SYSTEM OPTIONS

Chapter 2 identified 43 proven technologies for the treatment and disposal of special waste. For any given waste type (UCD category), between one and nine of those technologies were found to be applicable. For example, oily wastes with water (UCD 289) can be treated by rotary kiln incineration, fluidized bed incineration, wet air oxidation, or emulsion breaking. The first three technologies destroy the hazardous components in the waste by oxidizing the organics. Emulsion breaking reduces the volume of the hazardous waste by separating out the water, and sending just the oily component to incineration.

A system is developed by assigning each waste type to a particular technology (e.g., assigning UCD 289 to emulsion breaking). The system includes all the technologies to which incoming wastes are assigned (called the primary system) and the technologies which are required to treat and dispose of the liquid and solid intermediate streams generated by other technologies within the facility (called the secondary system).

A simplified example shows the complexities inherent in system development (Table 4.1). The first four UCD categories in Table 4.1 (UCD 111, 112, 113, 122) are treatable by one or more of three technologies (neutralization, precipitation, ion exchange). As Table 4.1 shows, there are eight different ways to assign wastes to technologies (Options 1-8), yielding three primary systems (AB, AC, ABC) capable of treating all four waste types. Each primary system will produce a liquid effluent (from neutralization and/or ion exchange) and a solid residue (from precipitation and/or ion exchange) requiring treatment by a secondary system. Four technologies are applicable to the liquid effluent, and three are applicable to the solid residues, yielding twelve possible secondary systems. Combining the three possible primary systems and the twelve possible secondary systems gives 36 system options applicable to the four waste types shown in Table 4.1.

The system would be even more complex if further treatment of the liquid effluent (e.g. by reverse osmosis) or of the solid residue (e.g. by filtration) were required prior to using the options listed in Table 4.1. Adding reverse osmosis and filtration would double the number of system options available for the secondary system, and increase the total number of system options (for the primary and secondary systems together) to 144.

System development continues to get more complex as the number of waste types and technologies increases. Overall, there are millions of different system options mathematically possible for the 81 different waste types using the 43 proven treatment and disposal technologies.

TABLE 4.1

EXAMPLE OF SYSTEM DEVELOPMENT

Technology	111	112	113	122
	Waste Types (UCD Category)			
A. Neutralization			●	
B. Precipitation	●	●		●
C. Ion Exchange	●	●		●

Systems Options - Primary System

Option	111	112	113	122	Primary System
	Waste Types				
1	B	B	A	B	AB
2	B	B	A	C	ABC
3	B	C	A	B	ABC
4	B	C	A	C	ABC
5	C	B	A	B	ABC
6	C	B	A	C	ABC
7	C	C	A	B	ABC
8	C	C	A	C	AC

Systems Options - Secondary System

Liquid Effluent		Solid Residue	
L_1	Discharge	S_1	Solidification/Engineered Landfill
L_2	Deepwell Injection	S_2	Solidification/Geologic Isolation
L_3	Evaporation	S_3.	Solidification/Warehouse Storage
L_4	Solidification		

Since it would be virtually impossible to evaluate such a vast number of possible system options carefully, four guidelines were used to limit the evaluation to the few best options:

1. For the first system, each waste type is assigned to the highest ranking technology capable of treating that waste type. The primary system can be selected directly from Table 3.3. Secondary system technologies are also chosen so that each intermediate waste stream is treated by the highest ranking technology.

2. For all systems, solid residues are sent to solidification and then to engineered landfill disposal.

3. For all systems, liquid effluent is sent to additional wastewater treatment and/or discharge, or is solidified.

4. Subsequent systems 2 and 3 are developed by changing the treatment of organics and inorganics in System 1 to improve the features of the system as a whole, particularly with regard to protecting human health and the environment.

   System 4, which is based on conventional European practice consists of the treatment technologies found in typical European integrated special waste treatment and disposal facilities.

These guidelines are discussed below.

ASSIGNMENT TO HIGHEST RANKING TECHNOLOGIES: SYSTEM 1

The technology selection and evaluation process described in Chapter 2 and 3 had as its outcome a list of the highest ranking technologies for each UCD category (Table 3.3). From a technology perspective (i.e., not including the system features discussed below), any primary system derived from Table 3.3 would better achieve OWMC's goals than any primary system including an assignment not on Table 3.3.

System 1 (Highest Ranking Component Technologies) is derived from Table 3.3. When there was more than one highest ranking technology applicable to a given waste type, technologies were selected so that the number of technologies in the primary system were minimized. The secondary system was also chosen using the highest ranking technologies; solidified materials were sent to engineered landfill. System 1 is described in detail later in this chapter.

USE OF SOLIDIFICATION AND ENGINEERED LANDFILL

All systems developed assume solidification and engineered landfill for disposal of residuals. The use of solidification is based on the premise of the study that only treated solid residues may be sent to disposal. Engineered landfill is used since it is currently OWMC's preferred disposal option, and making a definitive recommendation regarding disposal option is beyond the scope of this report.

TREATMENT OF LIQUID EFFLUENT

Liquid effluent from the OWMC facility may be discharged to surface water, deepwell injection, solidification or evaporation. Effluent will be tested prior to discharge to determine that the effluent is suitable for release to the receiving surface water body. If the effluent is not suitable for release, additional treatment (e.g., by reverse osmosis) would be performed and the effluent retested.

In developing system options, it is assumed that liquid effluent from activated sludge/powdered activated carbon, chemical oxidation, chemical reduction, solids dewatering (of inorganic wastes) and precipitation is sent to additional wastewater treatment prior to discharge. Aqueous effluent from emulsion breaking is sent to neutralization, the effluent from neutralization is solidified. Aqueous effluent from solvent extraction is sent to activated sludge/powdered activated carbon, and the separated solvent to incineration. Liquid effluent from other technologies treating organic waste (centrifugation and flocculation/sedimentation) is sent to the rotary kiln.

The above assignments are based on the ability of the technologies to treat typical wastes in the UCD categories they may receive. In actual design and operation of the OWMC facility, the quality of the liquid effluents may vary and further treatment may be required using technologies already in the system or using additional waste water treatment technologies such as reverse osmosis, evaporation or deep well injection.

REFINEMENT BASED ON SYSTEM FEATURES

Although System 1 is made up of the best component technologies, it may not be the best system when its features as a whole are considered. For instance, System 2, which uses less incineration by treating dilute aqueous/organic mixtures by activated sludge/powdered activated carbon or emulsion breaking, has fewer air emissions.

System features to consider in developing and evaluating system options include (in order of importance):

1. Quantity of discharge to air and surface water. The amount of gaseous emissions and liquid effluent discharged will vary depending on the technologies used in the system. Even though these discharges will comply with all applicable standards, they represent direct discharges to the environment, and should be minimized as much as possible to protect human health and the environment. Discharge quantity must be traded off with other system features, particularly the quantity of residuals sent to disposal.

2. Quantity of residuals to disposal. The amount of residuals sent to disposal will also vary depending on the technologies used in the system. In general, if gaseous emissions and liquid effluents are reduced, the quantity of residuals requiring disposal increases. Unlike liquid effluent and gaseous emissions, solidified residuals in an engineered landfill are not discharged to the environment. However, these materials require perpetual care to maintain protection of human health and the environment.

3. Number of technologies in the system. The fewer the technologies, the less complicated the system is to operate and monitor. The quantity of waste treated by the secondary system should also be considered. In general, a system that has fewer technologies and sends less waste to the secondary system provides less of a chance for error (including failure of the technology and operator error in transfer of waste residuals between technologies) and more protection of human health and the environment. A simpler system may also be more cost effective than a more complicated system.

The ability of the system to treat all types of waste was also considered in developing system options. The waste/technology combinations used in developing systems are based on UCD categories.

While the UCD system is one of the better waste categorization methods, it does have drawbacks. Each system option was examined to ensure that it is capable of treating all types of wastes which may be received.

SYSTEMS 2, 3 AND 4

Based on the above, an ideal system would have the following features:

- Only "A" technologies as the primary system.
- No secondary system required.
- No discharge to the environment.
- No residuals requiring disposal.

Unfortunately, such a system capable of destroying all types of waste completely does not yet exist. Any real system necessitates the use of several technologies as a primary system, (including "C" technologies), requires a secondary system, and produces discharges to the environment and residuals for disposal. It is possible, however, to modify System 1 (Highest Ranking Component Technologies) by modifying the selection of single technologies to improve the system as a whole. Based on this approach, two additional systems are proposed:

- System 2 (Highest Ranking Component Technologies - Improved) modifies System 1 by optimizing its system features.
- System 3 (Zero Surface Water Discharge) is similar to System 2 except that all liquid effluent is evaporated or solidified and disposed of instead of treated and discharged. This system is evaluated as System 3a (liquid effluent is solidified) and System 3b (liquid effluent is evaporated), since the features of each system are different.

Systems 2 and 3 represent changes in System 1 that reduce the risk to human health and the environment by minimizing air emissions, minimizing liquid effluents, and/or minimizing land disposal.

System 4 (Conventional European Practice) typifies the integrated European facilities that use a preference hierarchy to dispose of wastes: incineration if applicable; physical/chemical detoxification or volume reduction of non-incinerable wastes as applicable, and disposal as a last resort. This system was evaluated to compare the systems developed here with what is frequently done. System 4 also represents the system option generally preferred by OWMC.

A zero gaseous emission option is not possible, since incineration is the only option available for certain organic wastes (see Table 2.2). System 2, however, minimizes gaseous emissions by sending waste to higher-ranking technologies than incineration that produce less emissions wherever possible.

DESCRIPTION OF SYSTEM OPTIONS

Each of the four basic system options is capable of using proven technologies to treat all types of wastes that may be received by OWMC. The options differ, however, in the specific technologies used, the nature of the secondary system required, the quantity of liquid effluent and gaseous emissions generated, the amount of residuals requiring solidification and disposal, and the operating costs. This section describes each system option by the component technologies used and by the features of the system as a whole. The description of each system option is used to evaluate these options according to their component technologies and their system features. This information is also applicable when considering the environmental impact of the system options under the Environmental Assessment Act. A summary table and flow chart are provided for each system option.

In describing system options, it is useful to remember that, in general, organic wastes (Table 2.2), inorganic aqueous wastes (Table 2.3), and inorganic solids and sludges (Table 2.4) are treatable by different technologies. Organic wastes are treatable by thermal, biological, chemical and physical processes. Inorganic aqueous wastes can be handled by a different set of chemical processes, physical processes, and solidification. Inorganic solids and sludges, including treated residues from other technologies, are treatable by physical processes and by solidification.

SYSTEM 1: HIGHEST RANKING COMPONENT TECHNOLOGIES

In System 1, each UCD category was assigned to the highest ranking applicable technology (shown previously in Table 3.3). When there was more than one highest ranking technology, technologies were selected to minimize the number of technologies in the system. The secondary system was derived by sending residuals also to the highest ranking technology for each intermediate stream. The quantity of waste requiring additional treatment (per tonne of input waste) is given for each technology in Appendix D. System 1 is summarized in Table 4.2, a block flow diagram is given in Figure 4.1.

Organic wastes are treated by six technologies. These include one thermal process (rotary kiln incineration), one biological process (activated sludge/powdered activated carbon), and four physical processes (centrifugation, flocculation/sedimentation, emulsion breaking and solvent extraction). All, except rotary kiln, generate an organic residual which is sent to rotary kiln incineration (in some cases, after additional liquid/solid separation).

Inorganic aqueous waste and certain inorganic sludges are treated by five technologies -- four chemical processes (neutralization, precipitation, chemical oxidation and chemical reduction), and one

TABLE 4.2

SYSTEM 1: HIGHEST RANKING COMPONENT TECHNOLOGIES

WASTE TREATED

Technology	Quantity (t/a)
Centrifugation	52,642
Rotary Kiln	32,314
Activated Sludge/Powdered Activated Carbon	2,020
Solvent Extraction	510
Flocc./Sed.	500
Emulsion Breaking	4,500
Precipitation	55,152
Neutralization	10,300
Chemical Oxidation	1,860
Chemical Reduction	1,250
Solidification	71,754
Landfill	117,000

Summary of System Features

Number of Technologies:	12
Quantity - Primary System:	147,000 tonnes
Quantity - Secondary System:	86,000 tonnes
Total Gaseous Emissions:	454,000 tonnes
Total Surface Water Treatment/Discharge:	73,000 tonnes
Total Quantity to Land Disposal:	117,000 tonnes
Operating Cost:	$107/tonne of waste input

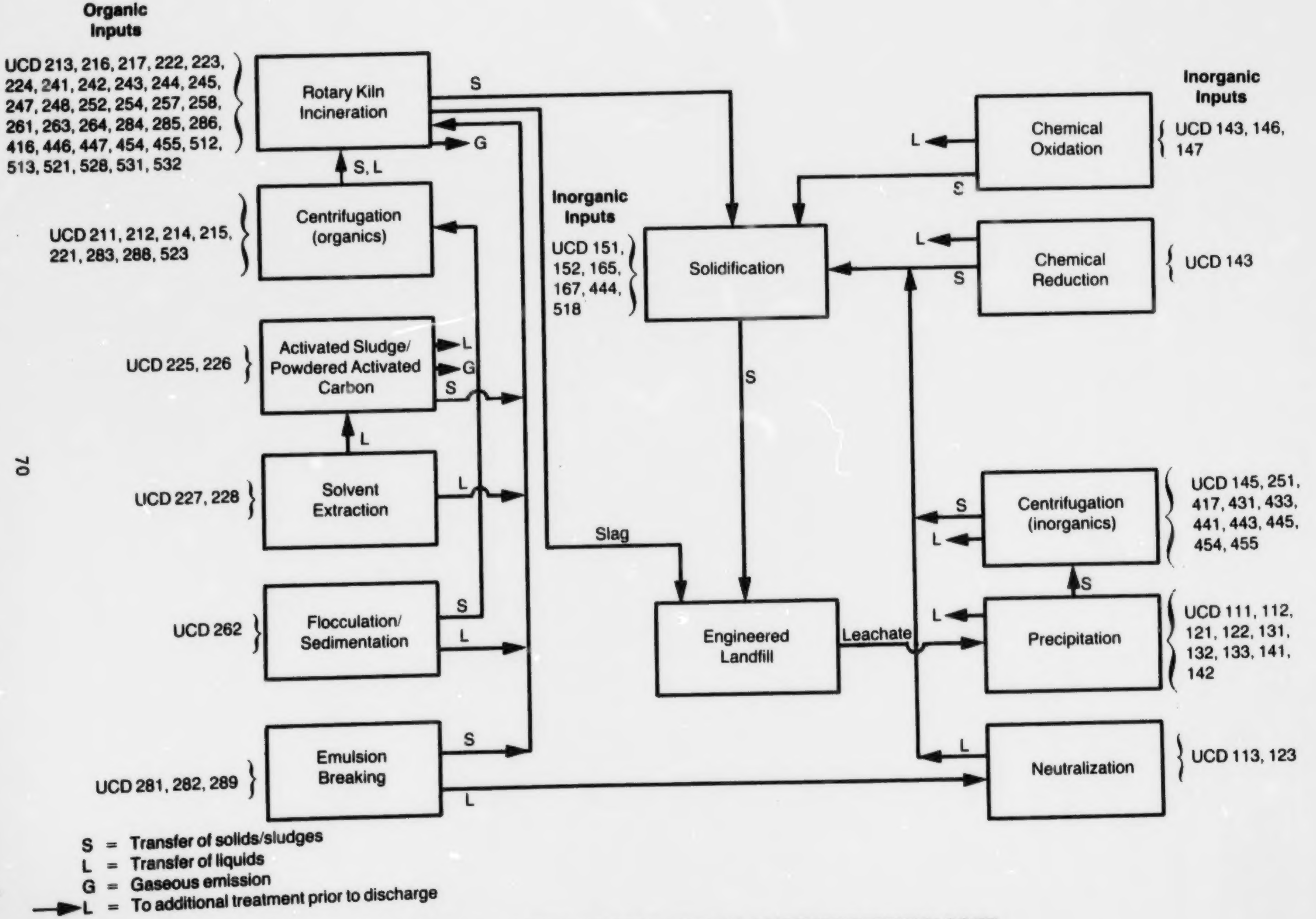
Organic Inputs
UCD 213, 216, 217, 222, 223, 224, 241, 242, 243, 244, 245, 247, 248, 252, 254, 257, 258, 261, 263, 264, 284, 285, 286, 416, 446, 447, 454, 455, 512, 513, 521, 528, 531, 532
Rotary Kiln Incineration
S
G
S, L
UCD 211, 212, 214, 215, 221, 283, 288, 523
Centrifugation (organics)
UCD 225, 226
Activated Sludge/ Powdered Activated Carbon
L
G
S
L
UCD 227, 228
Solvent Extraction
L
UCD 262
Flocculation/ Sedimentation
S
L
UCD 281, 282, 289
Emulsion Breaking
S
L
Inorganic Inputs
UCD 151, 152, 165, 167, 444, 518
Solidification
S
Slag
Engineered Landfill
Leachate
Inorganic Inputs
Chemical Oxidation
UCD 143, 146, 147
L
S
Chemical Reduction
UCD 143
L
S
Centrifugation (inorganics)
UCD 145, 251, 417, 431, 433, 441, 443, 445, 454, 455
S
L
S
Precipitation
UCD 111, 112, 121, 122, 131, 132, 133, 141, 142
L
Neutralization
UCD 113, 123
L
S = Transfer of solids/sludges
L = Transfer of liquids
G = Gaseous emission
→L = To additional treatment prior to discharge

FIGURE 4.1 SYSTEM 1: HIGHEST RANKING COMPONENT TECHNOLOGIES

physical process (solids dewatering by centrifugation). Residues and effluents from these technologies are either solidified (after additional solids/liquid separation or precipitation) or discharged. Inorganic laboratory waste (UCD 513) in prepackaged containers (called lab packs) is analyzed and reassigned to other UCD categories, as appropriate.

Inorganic solids and sludges are either solidified directly or dewatered before solidification. All treated residuals are solidified prior to disposal in an engineered landfill. Leachate from the landfill is treated as an inorganic aqueous waste and sent to precipitation.

SYSTEM 2: HIGHEST RANKING COMPONENT TECHNOLOGIES - IMPROVED

System 2 improves on System 1 by optimizing its system features. System 2 is summarized in Table 4.3 and a block flow diagram is given in Figure 4.2.

Organic wastes are treated by rotary kiln incineration except for those wastes amenable to activated sludge/powdered activated carbon or emulsion breaking. Activated sludge/powdered activated carbon and emulsion breaking were included in System 2 since they decrease the amount of waste sent to the rotary kiln and, therefore, decrease gaseous emissions.

Solvent extraction has been eliminated for the following reasons:

1. solvent extractable wastes can be incinerated

2. solvent extraction is a low scoring technology, and ranks only slightly better than incineration (C+ versus C).

3. solvent extraction is applicable to a relatively small waste stream (500 tonnes/year).

TABLE 4.3

SYSTEM 2: HIGHEST RANKING COMPONENT TECHNOLOGIES - IMPROVED

WASTE TREATED

Technology	Quantity (t/a)
Rotary Kiln	29,567
Activated Sludge/Powdered Activated Carbon	1,510
Emulsion Breaking	8,500
Neutralization	13,500
Precipitation	56,569
Chemical Oxidation	1,860
Chemical Reduction	1,250
Solidification	80,760
Landfill	131,000

Summary of System Features

Number of Technologies:	9
Quantity - Primary System:	147,000 tonnes
Quantity - Secondary System:	47,000 tonnes
Total Gaseous Emissions:	415,000 tonnes
Total Surface Water Treatment/Discharge:	65,000 tonnes
Total Quantity to Land Disposal:	131,000 tonnes
Operating Cost:	$114/tonne of waste input

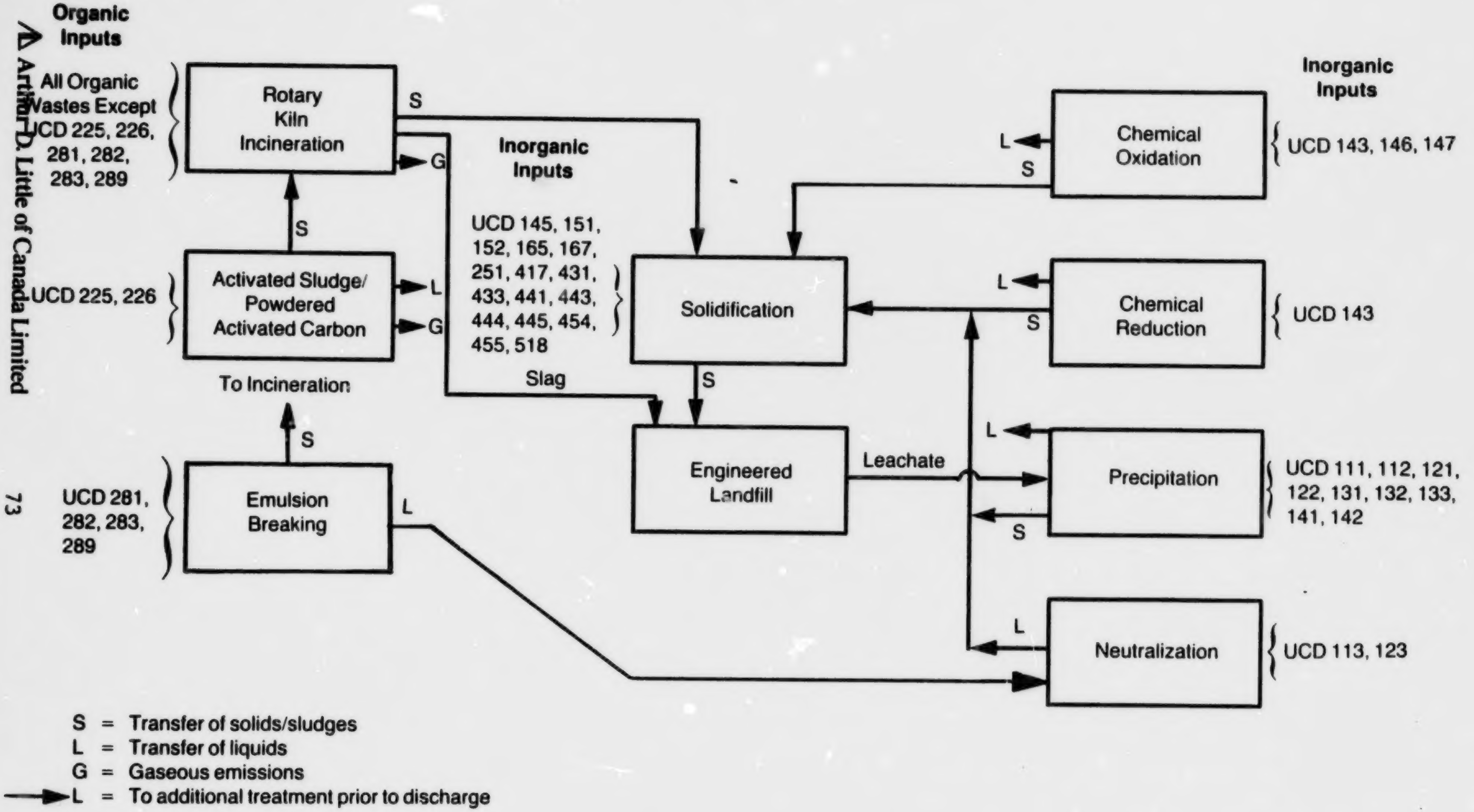

FIGURE 4.2 SYSTEM 2: HIGHEST RANKING COMPONENT TECHNOLOGIES — IMPROVED

Centrifugation and flocculation/sedimentation have been eliminated for organic waste, since both the solid residual and the separated liquid phase are sent to rotary kiln for secondary treatment, adding only to the complexity of the system with no resultant improvement in meeting OWMC's goals.

Inorganic aqueous wastes and inorganic sludges are treated in System 2 by neutralization, chemical oxidation, chemical reduction, precipitation, and solidification. The treatment is the same as System 1, except that wastes that were dewatered in System 1 are sent directly to solidification in System 2. This reduces the amount of liquid effluent generated and significantly reduces the quantity of waste requiring treatment by more than one technology. It does, however, increase the quantity of residuals to land disposal.

SYSTEM 3: ZERO SURFACE WATER DISCHARGE

System 2 has a liquid effluent stream that will be treated so that it meets Ontario's discharge standards. Systems 3a and 3b are based on System 2, except all liquid effluents are either solidified (System 3a) or evaporated (System 3b) rather than treated and discharged to reduce the risk to the environment further. Systems 3a and 3b are summarized in Table 4.4, and block flow diagrams are given in Figures 4.3 and 4.4.

In System 3a, all liquid effluents and solid residuals are solidified and disposed of. Precipitation of inorganic wastes is not required, since both the liquid and solid streams produced would be solidified. Activated sludge/powdered activated carbon is not used since the aqueous stream produced may not be amenable to solidification.

TABLE 4.4

SYSTEM 3: ZERO SURFACE WATER DISCHARGE*

WASTE TREATED

Technology	Quantity (t/a)
Rotary Kiln	30,835
Emulsion Breaking	8,500
Neutralization	13,500
Chemical Oxidation	1,860
Chemical Reduction	1,250
Solidification	A:139,711 B:69,391
Landfill	A:225,000 B:113,000
Precipitation	B:54,805
Evaporation	B:88,060

Summary of System Features	A	B
Number of Technologies:	7	9
Quantity - Primary System:	147,000 tonnes	147,000 tonnes
Quantity - Secondary System:	52,000 tonnes	122,000 tonnes
Total Gaseous Emissions:	432,000 tonnes	506,000 tonnes
Total Surface Water Treatment/Discharge:	0 tonnes	0 tonnes
Total Quantity to Land Disposal:	225,000 tonnes	113,000 tonnes
Operating Costs:	$173/tonne of waste input	$116/tonne of waste input

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* Technologies and quantities specific to System 3a (Solidification) are designated with an "A"; System 3b (Evaporation) with a "B".

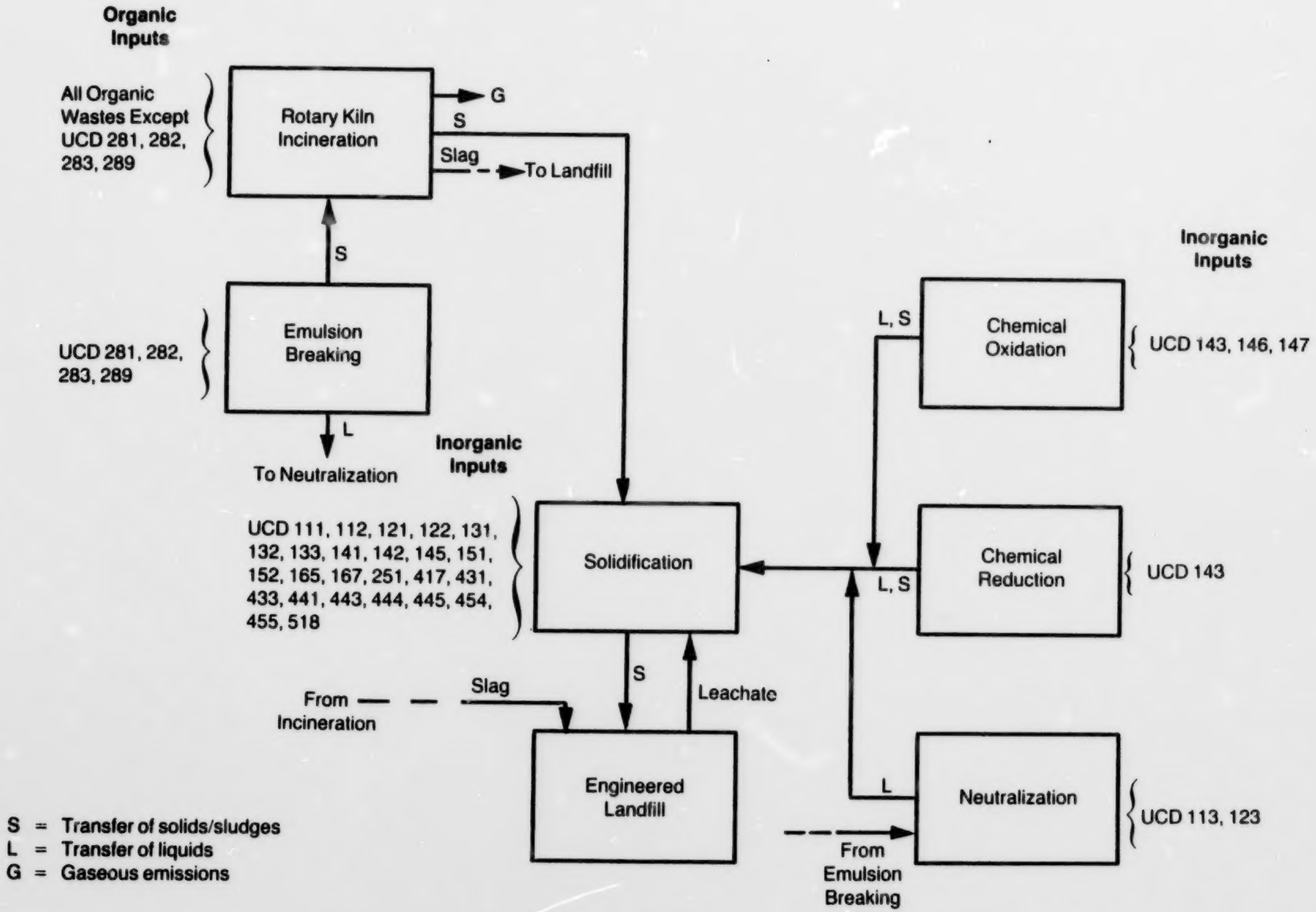

FIGURE 4.3 SYSTEM 3a: ZERO SURFACE WATER DISCHARGE — SOLIDIFICATION

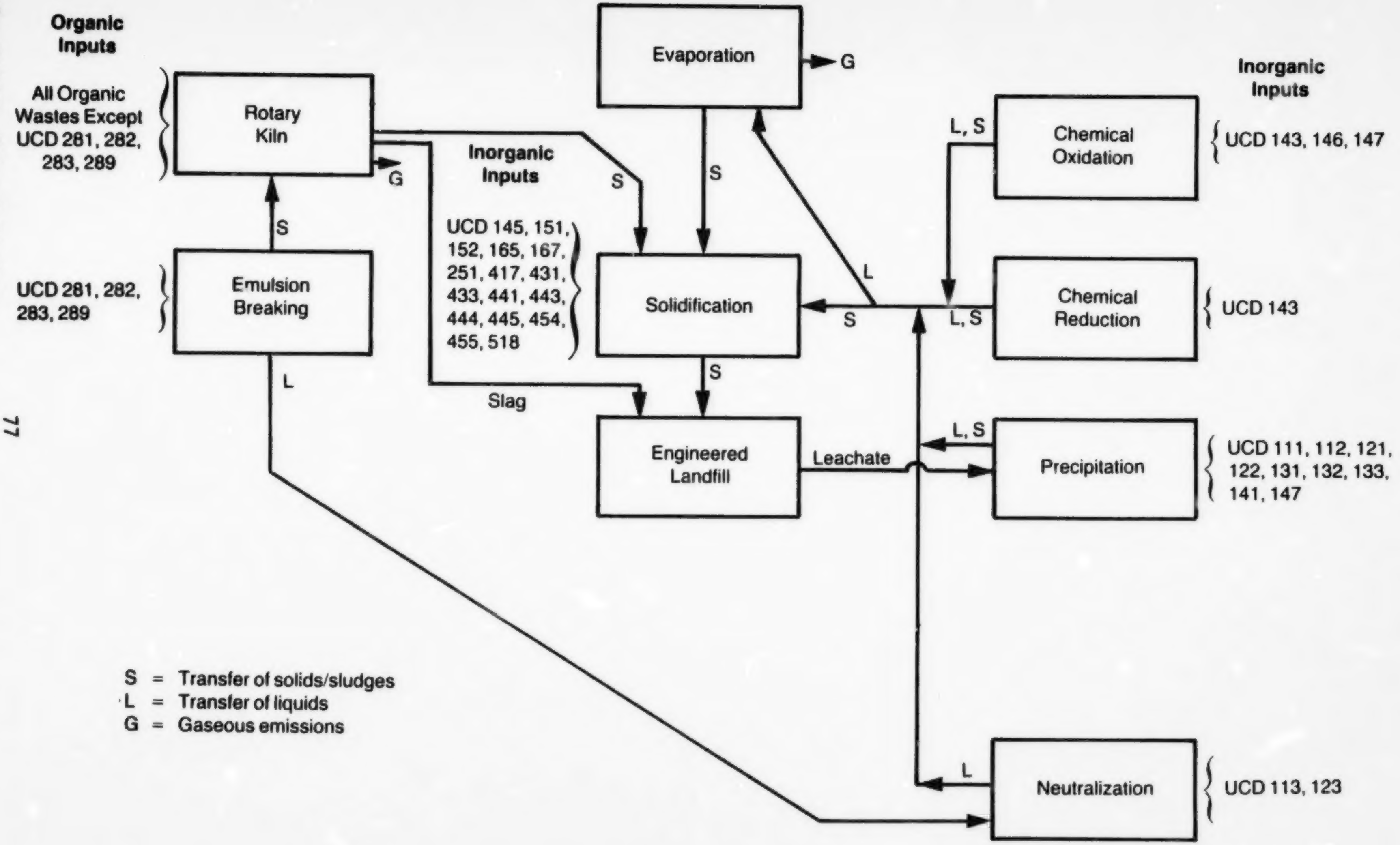

FIGURE 4.4 SYSTEM 3b: ZERO SURFACE WATER DISCHARGE — EVAPORATION

In System 3b, all liquid effluents are evaporated. Precipitation is still required because only the liquid stream is evaporated; the solid stream is sent to solidification as in System 2. The concentrated blowdown from the evaporator is solidified and disposed of. Activated sludge/powdered activated carbon is not used since the aqueous stream produced would contain organics and is not safely treatable by evaporation.

It may also be desirable to send aqueous solutions with heavy metals (UCD 141), aqueous solutions with other metals (UCD 142) and brine (UCD 145) to evaporation, prior to solidification. This would reduce the quantity of waste requiring solidification, and therefore reduce the quantity of waste sent to land disposal. These wastes are sent to solidification in System 3, since solidification is a higher ranking technology than evaporation.

SYSTEM 4: CONVENTIONAL EUROPEAN PRACTICE

System 4 reflects the system generally preferred by OWMC and it typifies the integrated facilities that treat wastes in accordance with a preference hierarchy--incineration if applicable; physical/-chemical detoxification or volume reduction of non-incinerable wastes as applicable; disposal as a last resort. This preference hierarchy was also published by the U. S. Environmental Protection Agency prior to the passage of the Resource Conservation and Recovery Act (RCRA) and is implicit in recent amendments to RCRA. Although traditional US practice relies heavily on engineered landfill and deepwell injection, newer treatment plants use more physical and chemical processes and reduce reliance on injection and landfill. Two major differences between the European facilities and System 4 are that solidification is used for all waste prior to disposal and emulsion breaking is used for certain wastes to reduce the load on the incinerator. System 4 is summarized in Table 4.5 and a block flow diagram is provided in Figure 4.5.

TABLE 4.5

SYSTEM 4: CONVENTIONAL EUROPEAN PRACTICE

WASTE TREATED

Technology	Quantity (t/a)
Rotary Kiln	30,835
Emulsion Breaking	8,500
Dewatering*	45,642
Precipitation	55,144
Neutralization	13,500
Chemical Oxidation	1,860
Chemical Reduction	1,250
Solidification	74,603
Landfill	121,000

Summary of System Features

Number of Technologies: 9
Quantity - Primary System: 147,000 tonnes
Quantity - Secondary System: 85,000 tonnes
Total Gaseous Emissions: 432,000 tonnes
Total Surface Water Treatment/Discharge: 71,000 tonnes
Total Quantity to Land Disposal: 121,000 tonnes
Operating Cost: $108/tonne of waste input

* by centrifugation or filtration, as appropriate.

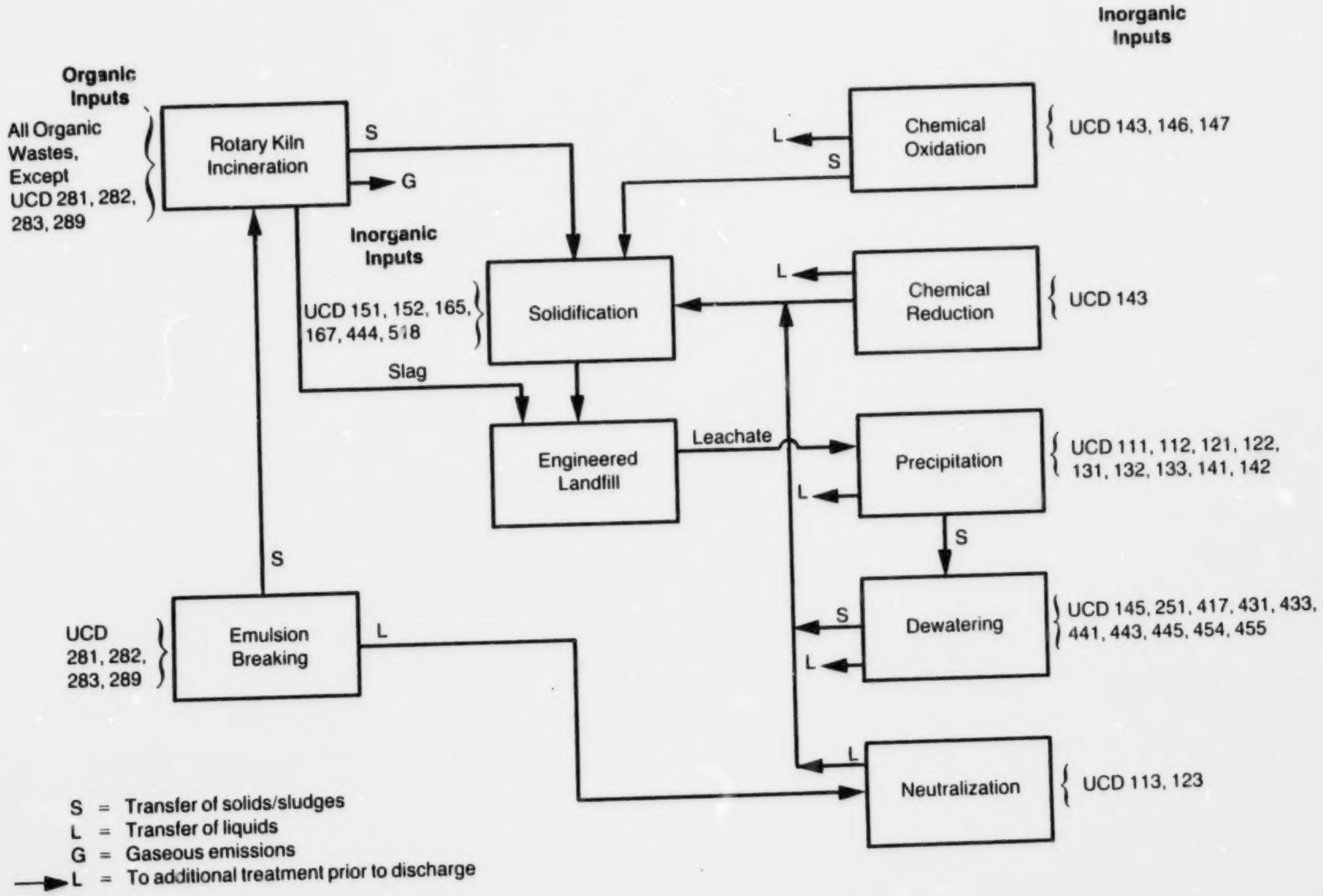

FIGURE 4.5 SYSTEM 4: CONVENTIONAL PRACTICE

All organic wastes are sent to rotary kiln incineration, except for waste oil and mixed oil (UCD 281), oily tank bottoms (UCD 282), oil, mud, sediment, and water (UCD 283), and oily wastes with water (UCD 289), which are first sent to emulsion breaking. Inorganic aqueous wastes are sent to chemical treatment (neutralization, precipitation, chemical reduction, chemical oxidation) or physical treatment (dewatering).

Inorganic solids and sludges are sent to solids dewatering or directly to solidification. All treated residues are solidified and disposed of in a secure landfill.

EVALUATION OF SYSTEM OPTIONS

This section evaluates system options in two ways: by component technologies and by system features. The evaluation by component technologies examines the system options using the results of the technology ranking in Chapter 3. The evaluation by system features compares the system options based on the overall characteristics of the system as a whole. Conclusions and recommendations from the evaluation are presented in Chapter 5.

Each part of the evaluation addresses how well the system options meet OWMC's goals. The technology ranking in Chapter 3 evaluates the technologies according to criteria that were specifically developed to measure how well OWMC's goals are achieved. The system features, used to develop and compare system options are, in some ways, comparable to the technology evaluation criteria. The relationship between the system features and the technology evaluation criteria is discussed below.

The evaluation of system options provides information applicable to the Environmental Assessment Act.(66) This Act requires that the "advantages and disadvantages to the environment" of the various system options be evaluated. Environmental impacts are addressed by several of the technology evaluation criteria (see Figure 3.1) and by several system features (including quantity of gaseous emissions, liquid effluents and residuals requiring land disposal). Systems using higher scoring component technologies and which minimize gaseous emissions, liquid effluents and residuals to land disposal will have the fewest environmental impacts.

EVALUATION BY COMPONENT TECHNOLOGIES

Table 4.6 summarizes the technologies used in each system option to treat organic wastes, inorganic aqueous wastes, and inorganic solids, sludges and residuals. The table gives the letter grade assigned to each technology in Chapter 3 and the percentage of each waste group (organic, inorganic aqueous, or inorganic solids, sludges and residuals) treated by each technology. An overall grade is also given in each waste group for each system. The overall grade was determined by considering the amount of waste handled by technologies of different letter grades. Technologies which receive a higher percentage of the waste more strongly influence the overall grade.

All of the systems receive a "C" for their treatment of organic wastes, since most organic wastes are sent to rotary kiln incineration in all systems. The fact that 14% of the organic waste in System 1 is treated by centrifugation and flocculation/sedimentation did not affect the overall grade of the system since both the liquid effluent and solid residues generated by these technologies (for organic wastes) are subsequently sent to the rotary kiln. The presence of activated sludge/powdered activated carbon and emulsion breaking in Systems 1 and 2 was not significant enough to affect the overall grade, as most of the waste is still handled by the rotary kiln.

TABLE 4.6

SYSTEMS EVALUATION BY COMPONENT TECHNOLOGIES

TECHNOLOGIES USED (RANKING) - AMOUNT

SYSTEM NAME	ORGANIC WASTES		INORGANIC AQUEOUS WASTES		INORGANIC SOLIDS AND SLUDGES, RESIDUALS	
1. Highest Ranking Component	Centrifugation (A)	13%	Precipitation (A)	70%	Solidification (A-)	32%
Technologies	Rotary Kiln (C)	71%	Neutralization (A)	13%	Centrifugation (A)	16%
	Activated Sludge/Powdered		Centrifugation (A)	13%	Landfill (B)	52%
	Activated Carbon (B)	4%	Chemical Oxidation (C)	2%		100%
	Solvent Extraction (C+)	1%	Chemical Reduction (B)	2%		
	Flocculation/Sed. (A)	1%				
	Emulsion Breaking (B)	10%				
		100%		100%		
Overall Grade:	C		A		B+	
2. Highest Ranking Component	Rotary Kiln (C)	75%	Neutralization (A)	16%	Solidification (A-)	38%
Technologies-Improved	Activated Sludge/Powdered		Precipitation (A)	68%	Landfill (B)	62%
			Solidification (A-)	12%		
	Activated Carbon (B)	4%	Chemical Oxidation (C)	2%		100%
	Emulsion Breaking (B)	21%	Chemical Reduction (B)	1%		
		100%		100%		
Overall Grade:	C		A		B+	
3a. Zero Surface Water Discharge	Rotary Kiln (C)	78%	Neutralization (A)	16%	Solidification (A-)	38%
(Solidification)			Solidifcation (A-)	80%	Landfill (B)	62%
	Emulsion Breaking (B)	22%	Chemical Oxidation (C)	2%		100%
		100%	Chemical Reduction (B)	1%		
				100%		
Overall Grade:	C		A-		B+	

TABLE 4.6 (continued)

TECHNOLOGIES USED (RANKING) - AMOUNT

SYSTEM NAME	ORGANIC WASTES		INORGANIC AQUEOUS WASTES		INORGANIC SOLIDS AND SLUDGES, RESIDUALS	
3b. Zero Surface Water Discharge (Evaporation)	Rotary Kiln (C)	78%	Neutralization (A)	19%	Solidification (A-)	38%
	Emulsion Breaking (B)	22%	Precipitation (A)	77%	Landfill (B)	62%
		100%	Chemical Oxidation (C)	3%		100%
			Chemical Reduction (B)	2%		
			Evaporation (B)	*		
				100%		
Overall Grade:	C		A-		B+	
4. Conventional European Practice	Rotary Kiln (C)	78%	Precipitation (A)	67%	Solidification (A-)	32%
			Neutralization (A)	16%	Filtration (A-)	16%
	Emulsion Breaking (B)	22%	Filtration (A-)	13%	Landfill (B)	52%
		100%	Chemical Oxidation (C)	2%		100%
			Chemical Reduction (B)	2%		
				100%		
Overall Grade:	C		A-		B+	

* for treatment of liquid effluent

Most inorganic aqueous wastes are sent to "A" technologies. Systems 1, 2 and 4 were given an overall grade of "A" for treatment of inorganic aqueous wastes, as only a small portion (5%) of the wastes are sent to "B" and "C" technologies. Systems 3a and 3b received an "A-" since a larger portion of their inorganic aqueous wastes were treated by lower scoring technologies (solidification in System 3a; and evaporation in System 3b).

All systems receive a "B+" for their treatment of inorganic solids, sludges and residuals. The only difference between the systems is that Systems 2 and 3a do not separate solids and liquids prior to solidification.

The overall grades assigned to each system are subjective and are significant only in that they facilitate comparison of the system options. The fact that a system receives a "C" rather than an "A" does not mean that the system is inadequate in its ability to treat the waste. All systems and technologies evaluated by OWMC use proven technologies to treat all wastes received in an environmentally acceptable manner.

EVALUATION BY SYSTEM FEATURES

Each system option has features, in addition to its component technologies, which can be used to characterize the system as a whole. These system features include (in order of importance):

- Quantity of gaseous emissions.
- Quantity of liquid effluent treated and discharged to surface water.

- Quantity of residuals to land disposal.
- Quantity of waste handled by the secondary system.
- Number of technologies in the system.
- Operating cost.

These system features can be compared to OWMC's goals and to the technology evaluation criteria developed in Chapter 3. The quantity of gaseous emissions, liquid effluent treated and discharged, and residuals to land disposal describe the impact of the facility on human health and the environment, as do the abnormal events and normal events criteria for technologies. These features also relate to OWMC's first two goals of protecting human health and the environment. The number of technologies in the system and the quantity of waste handled by the secondary system describe the complexity of the system and are similar to the technical reliability criterion for technologies (see Table 3.1). Less complex systems reduce the chance for human error and, therefore, provide greater protection to human health and the environment. The cost feature relates to OWMC's third goal, and is similar to the relative operating cost criterion for technologies. The operational reliability, input flexibility and operational flexibility criteria are not comparable to any system feature since they are either technology specific or would be the same for every system option.

Table 4.7 summarizes the system options according to their system features. To facilitate the comparison of system options, a letter grade is also given for each number in Table 4.7. Letter grades were determined by assigning an "A" to the lowest number in each column and a "C" to the highest number. Letter grades for numbers in between were established based on how close they were to the "A" or "C" value in their column. Quantity of waste in the primary system is not specified since these numbers are all the same (147,000 t/a).

TABLE 4.7

SYSTEM EVALUATION BY SYSTEM FEATURES*

System Name	# of Techn.	Quantity In Secondary System (tonne)	Wastewater Treatment/ Discharge (tonne)	Gaseous Emissions (tonne)	Land Disposal (tonne)	Operating Cost ($/tonne)
1. Highest Ranking Component Technologies	12 (C)	86,000 (B)	73,000 (C)	454,000 (B+)	117,000 (A-)	107 (A)
2. Highest Ranking Component Technologies-Improved	9 (B)	47,000 (A)	65,000 (B-)	415,000 (A)	131,000 (B+)	114 (B+)
3. Zero Surface Water Discharge						
a. Solidification	7 (A)	52,000 (B+)	0 (A)	432.000 (A-)	225,000 (C)	173 (C)
b. Evaporation	9 (B)	122,000 (C)	0 (A)	506,000 (C)	113,000 (A)	116 (B+)
4. Conventional European Practice	9 (B)	85,000 (B)	71,000 (C)	438,000 (A-)	121,000 (A-)	108 (A)

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* The figure in parenthesis below a number is a letter grade used to compare the number to other numbers in the same column.

All five system options are considered to be acceptable systems, based on the six system features. In fact, the improvements made on System 1 in developing the other systems did not change any system feature by more than 50% for any of the systems with the exception of liquid effluent treatment/discharge in Systems 3a and 3b. A discussion of the system features of each system option follows.

System 1 (Highest Ranking Component Technologies) has moderate gaseous emissions compared to other system options. The quantity of effluent discharge to surface water or treatment is highest of all systems options while the use of land disposal is comparable to the system option that least relies on land disposal. System 1 uses more technologies than any of the other system options, but its total operating cost is the lowest of all systems, because of its relatively lower usage of expensive and lower scoring technologies such as incineration, solidification and engineered landfill. Overall System 1 cannot be considered the best system option because:

1. it does not minimize air emission, the most important of the system features in the evaluation hierarchy, compared to other system options;

2. it does not minimize liquid effluent, the second most important of the system features in the evaluation hierarchy, which could counterbalance the moderate ranking in air emission quantity;

3. it ranks amongst the best of the system options only in use of land disposal and cost, which are relatively less important compared to the other system evaluation features.

System 2 (Highest Ranking Component Technologies - Improved) is the best system in terms of gaseous emissions, and has moderate effluents and land disposal requirements. In addition, System 2 has a moderate number of technologies and the least waste in the secondary system, simplifying the operations. Gaseous emissions are reduced from System 1 primarily since Oily Mud, Sediment and Water (UCD 283) is sent to emulsion breaking in System 2 rather than centrifugation and rotary kiln incineration. System 2 also includes activated sludge/powdered activated carbon, giving it lower emissions than System 3a and 4. Liquid effluent, as well as quantity of waste in the secondary system, in System 2 are less than in Systems 1 and 4 since certain inorganic wastes are solidified without prior dewatering. The additional amount to solidification, however, increases the quantity of residuals to land disposal and increases operating costs.

System 3a (Zero Surface Water Discharge - Solidification) is the least complex of the five systems. It eliminates discharge to surface waters by solidifying all liquid effluents. Fewer technologies are required; neither dewatering nor precipitation are needed since both the sludge and liquid streams they generate are solidified. In addition, activated sludge/powdered activated carbon is not used since the liquid stream generated would not be amenable to solidification. As a result, gaseous emissions are higher for this option than in System 2. Land disposal requirements and operating costs are high compared to other options due to the large amount of material which is solidified.

System 3b (Zero Surface Water Discharge - Evaporation) eliminates discharge to surface waters by evaporating all liquid effluents. Gaseous emissions are high since the evaporator as well as the rotary kiln contribute to the total. Like System 3a, activated sludge/powdered activated carbon is not used since the liquid effluent produced may not be treatable by evaporation. The quantity of waste in the secondary system is high compared to other systems since the amount includes all of the liquid effluent sent to the evaporator plus the evaporator blowdown which is solidified.

System 4 (Conventional European Practice) generates more gaseous emissions and liquid effluent requiring treatment and discharge than System 2. This is because System 2 uses activated sludge/powdered activated carbon to reduce the load on the incinerator, and does not dewater certain inorganic wastes prior to solidification. Dewatering these inorganic wastes in System 4 also increases the amount of waste handled by the secondary system, and decreases the operating cost and amount sent to land disposal, as compared to System 2.

Of these systems, System 2 best meets OWMC's goals. It minimizes air emissions over all systems, and effluent discharge is also minimized when compared to other options except "zero discharge" options. The land disposal for System 2 is somewhat greater than Systems 1, 3b or 4 but this is a relatively less important factor. System 2 has the least amount of material that requires more than one treatment, and requires a moderate level of complexity (number of technologies) when compared to System 3a.

If OWMC decides to use a zero surface water discharge option, it is necessary to decide between systems which are strong in one area but weak in another. System 3a offers a small decrease in gaseous emissions but a large increase in operating cost and quantity to land disposal. Alternatively, System 3b offers lower land disposal amounts and operating costs, but has a moderate increase in gaseous emissions and a large increase in the quantity of waste in the secondary system.

Conclusions and recommendations from the analysis of system options by their technology components and system features are given in Chapter 5.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions and recommendations from the analyses conducted during this study.

CONCLUSIONS

- System 2 (Highest Ranking Component Technologies--Simplified) best meets OWMC's goals and objectives as described in this report. It has the least amount of air emissions and quantity of residuals requiring treatment by the secondary system. It also generates 11% less liquid effluent than System 1 (Highest Ranking Component Technologies) and 8% less than System 4 (Conventional European Practice). Its drawback compared to the other systems is that it requires about 12% more land disposal than System 1, and about 8% more than System 4, and has a slightly higher operating cost (about 6% more than Systems 1 and 4).

- The conceptual system described by OWMC (System 4--Conventional European Practice), consisting of rotary kiln incineration, comprehensive physical and chemical treatment, and engineered landfill, corresponds to conventional European practice for safe and efficient treatment and disposal of special wastes. In addition, emulsion breaking is used to reduce the load on the rotary kiln, and solidification is used for all residuals prior to land disposal. Although these are not normally included in Europe, they provide additional environmental protection since air emissions and potential for groundwater contamination are reduced.

However, to a minor extent, System 2 is more effective in meeting OWMC's goals and objectives. It makes improvements over System 4 in the most important system features (quantity of gaseous emissions and liquid effluent generated).

- The effectiveness of the conceptual system preferred by OWMC in meeting OWMC's goals and objectives might be improved by using activated sludge/powdered activated carbon for treatment of aqueous solutions with less than 10% halogenated or non-halogenated residues (UCD 225, 226). This decreases the amount of waste sent to the rotary kiln thereby decreasing gaseous emissions. The benefit of adding activated sludge/powdered activated carbon will depend on the quantity of waste received which is treatable by this technology.

- The effectiveness of the conceptual system preferred by OWMC in meeting OWMC's goals and objectives might be improved by solidifying rather than dewatering certain inorganic wastes. The main benefit of dewatering inorganic wastes is that it reduces the quantity of liquid sent to solidification, thereby reducing treatment cost and the quantity of material requiring land disposal. Solidifying these wastes directly, however, reduces liquid effluent by 8%, which is a more important objective than reducing cost or quantity sent to land disposal.

- If OWMC decides to select a zero discharge option, the choice between solidification and evaporation of liquid effluent is not clear-cut. Solidification of liquid effluent produces about 15% fewer gaseous emissions than evaporation, has fewer component technologies, and has about half as much waste in the secondary system. However, it sends nearly twice as many residuals to land disposal and is 50% more expensive. Although reducing gaseous emissions is a greater priority than reducing quantity to land disposal or operating cost, it is not clear whether a 15% decrease in gaseous emissions offsets a two-fold increase in land disposal and a 50% increase in operating cost.

- The content of the Proctor and Redfern "Generic Process Technologies Studies" is still basically correct except that cost estimates are out of date, certain emerging technologies are not covered, and wastes have been mis-assigned to technologies in some cases. Updated technology discussions are given in Appendix C.

RECOMMENDATIONS

- OWMC should consider adding activated sludge/powdered activated carbon for treatment of aqueous solutions with less than 10% halogenated and non-halogenated residues (UCD 225, 226). However, since information currently available on waste types and quantities is insufficient to determine how much waste would actually be suitable for treatment by this technology, it is recommended that this decision be made after start-up when more is known about the wastes that are actually received.

- OWMC should consider solidifying rather than dewatering inorganic solids and sludges, since this decreases the amount of liquid effluent generated.

- For each of the generic technologies to be used, vendor-specific variations should be investigated.

- The market survey data developed by OWMC should be analyzed further for available information on specific waste compositions, beyond the UCD categories. Depending on the quality and quantity of the information, the possibilities for material recovery should be examined and facility design and operation should be modified, as appropriate.

- Because of the importance of the abnormal events and normal operations criteria to the evaluation conducted in this study, the attainment of these criteria should be re-evaluated when the site and the precise system design is chosen. Different sites may be sensitive to different abnormal events or normal operations, and the results of this analysis may change if site-specific factors are considered.

- Development and demonstration of innovative treatment technologies is an active area of research in Canada and elsewhere. OWMC should update their list of proven technologies periodically to incorporate novel technologies when they become proven. As of the date of submission of this report in Fall 1986, for example, sequencing batch reactors and liquid ion exchange, both not proven as of January 1, 1985, may now be considered proven.

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APPENDIX A

TYPICAL WASTE STREAMS AND RESIDUALS BY UCD CATEGORY

APPENDIX A

TYPICAL WASTE STREAMS AND RESIDUALS BY UCD CATEGORY

UCD CATEGORY	DESCRIPTION	TYPICAL WASTE
111	Acidic Solution with Heavy Metals	Pickle Liquor Rinse Water
112	Acidic Solution with Other Metals and Non-Metals	Demineralizer Regenerant
113	Other Acidic Solutions	Boiler Stack Scrubber Water with Dilute Carbonic Acid (H_2CO_3)
121	Alkaline Solution with Heavy Metals[a]	Rinse Waters from Surface Cleaning of Metals
122	Alkaline Solution with Other Metals	Demineralizer Regenerant
123	Other Alkaline Solution	Cleanup Water from Lime or Cement Kiln
131	Spend Etchant/Plating Solutions, Acid	Ammonia Based, Containing Copper, Tin, Lead and/or Cadmium
132	Spent Etchant/Plating Solution, Alkaline	Contain Strong Complexing Agent and Copper, Tin, Lead and/or Cadmium
133	Spent Pickle Liquor from Ferrous and Non Ferrous Metals	Strong Acids with Iron, Flouride Hydrochloric Acid (HCl), Sulfuric Acid (H_2SO_4), Nitric Acid (HNO_3)
141	Aqueous Solutions with Heavy Metals[b]	Cleaning Solutions from Tanks, Trucks, or Railroad Tankers
142	Aqueous Solutions with Other Metals	Rinse Water from Heat Treating Salt Baths, Contain Barium, Aluminum
143	Aqueous Solutions with Reactive Anions[c]	Bleaching Solutions Containing Sulfite, Chlorite, Flouride, Bromate
145	Brine[d]	Salt Solutions After Neutralization or Chlor/Alkali Productions

UCD CATEGORY	DESCRIPTION	TYPICAL WASTE
146	Solution Containing Cyanide[e]	Plating Baths
147	Solution Containing Sulfides	Plating Baths
151	Inorganic Solids	Foundry Sand
152	Inorganic Solids Chemicals	Aged or Off Spec. Chemicals including Lime, Caustic Soda and Partial Containers of Laboratory Size
165	Spent Catalyst[f]	Maybe Carbon or Metal
167	Other Inorganic Waste	Ash and Construction Residue
211	Halogenated Solvents with Heavy Metals[g]	Methylene Chloride, 1, 1, 1-Trichloroethane Used for Metal Cleaning
212	Halogenated Solvents with Other Metals[g]	Surface Cleaning and Degreasing Solvents
213	Halogenated Solvents	Freon and Other Solvents Used in Chemical Processing
214	Non-Halogenated Solvents with Heavy Metals[g]	Toluene, Benzene, Xylene Contaminated with Catalysts
215	Non-Halogenated Solvents with Other Metals[g]	Acetone, Methylisobutylketone (MIBK) used in Paint & Varnish Formulation
216	Non-Halogenated Solvents	Methylethylketone (MEK) Solvents Contaminated with Dirt
222	Organic Liquids with Halogens Only	Chloroform, Carbon Tetrachloride
223	Organic Liquids with Metals Only[h]	Nickelcarbonyl, Methyl Mercury
224	Other Organic Liquids	Creosote and Other Polyaromatic Hydrocarbons
225	Aqueous Solution with non-Halogenated Residues Less Than 10%[i]	Laboratory Mixtures

UCD CATEGORY	DESCRIPTION	TYPICAL WASTE
226	Aqueous Solution with Halogenated Residues Less Than 10%[i]	Waste or Rinse Waters After Degreasing
227	Aqueous Solution with Non-Halogenated Organic Residue Greater Than 10%[j]	Laboratory Mixtures
228	Aqueous Solution with Halogenated Organic Residue greater than 10%[j]	Wash or Rinse Waters after Degreasing
241	Pesticides and Wastes	Partial Containers, Tank Washings, Off Spec. Product, etc.
242	PCB Oils and High Strength (over 500 ppm) Liquids	From Transformers and Capacitors
243	Pharmaceuticals and Waste	Off-Spec. Drugs, Cleanup Waters, etc., Includes Items such as Vitamins
244	Photochemicals and Waste[k]	Most Solutions Non-Toxic Except those with Silver
245	Off-Spec or Aged Organics	Can Include Solids or Liquids. Generally in Containers
247	Halogenated Still Bottoms	Spent Solvent or Waste Oil Recovery
248	Non-Halogenated Still Bottoms	Solvent Recovery Operations
251	Tannery Wastes	Solutions with Hexavalent Chromium, Alkaline Solutions
252	Solid or Sludge Tannery Wastes[l]	Leather Shavings with Chrome, Other Sludge
254	Adhesives or Glue	Waste Glues including Some Urea-Formaldehyde Waste. Some May have Phenol and Most are Aqueous. Solids are Non-Hazardous
257	Phenolic Wastes	Phenolic Oil, Toluene Diisocyanate Residue
258	Waste Tar and Residues	

UCD CATEGORY	DESCRIPTION	TYPICAL WASTE
261	Polymeric Resin	Polyester, Urethane, Etc.
262	Latex Wastes	Cleanup Water, Paint, Latex and Acrylic Resins
263	Other Polymeric Wastes	Cleanup, Kettle Bottoms, Thermoplastic Resins, Etc.
264	Thermoset Wastes	Urea-Formaldehyde and Thermoset Wastes
281	Waste Oil and Mixed Oil	Used Automotive Oil, Cutting Oil-May Contain Solvents or Metals
282	Oily Tank Bottoms	Crude Oil or Sludge from Storage
283	Oily Mud, Sediment and Water	Crude Oil Tanker Cleaning
284	Oily Acidic Solids	Solids Which Result from Emulsion Breaking and Re-Refining
285	Oily Alkaline Solids	Mostly Refining Solids from Processing Line
286	Oily/Water Separator Sludge	Oil Cooled Heavy Inorganics
287	Oily Sludge	May be from Sources Other than Oil Processing, Etc. Foods and Rendering
288	Oily Wastes With Heavy Metal Contaminants	Steel Rolling Mill Sludges and Scale
289	Oily Wastes with Water	Emulsions, Cleanup Water from Garages, Cooling Waters
416	Ink Sludge[m]	Sludge Could Contain Solvents, Lead, Cesium, Chromium
417	Alum and Gypsum Sludges	Waste Water Phosphate Removal Sludge
431	Heavy Metal Sludge	Similar to that in 113, 141.
433	Other Metal Sludges	Ferric Chloride, Aluminum Oxide, etc.
441	Lime Sludges	From Treatment of Acids and Bases, Similar to 431
443	Sulphur Sludge	Desulphurization of Flue Gas Nonreactive but Very Low Bearing Strength

UCD CATEGORY	DESCRIPTION	TYPICAL WASTE
444	Cyanide Bearing Sludge[n]	Pot Liners from Aluminum Reduction and Scrubber Sludge from Blast Furnace
445	Plating or Metal Finishing Sludge	From Treatment of Metal Contaminated Solutions
446	Degreasing Sludge	Grease and Oily Soil containing Trichloroethane (TCE)
447	Tetraethyl Lead Sludge[m]	Tank Bottoms
454	Paint Sludge[m]	Drum Bottoms, Spills, Cleanup, etc.
455	Paint Sludge without Heavy Metals[m]	Mostly Latex
509	Gas Cylinders or Containers	Oxygen Cylinders - Empty
512	Spill Cleanup	Oil/Soil Mixture
513	Laboratory Waste Chemicals	Partially Full Small Containers
518	Dust Collector Wastes	Dry Lime from Dust Control Baghouse
521	Spent Cartridge Filters	Air Cleaning Filters on Ventilation System
523	Tank Bottom Sediments[o]	Some may Contain Flammable Organics
528	Pathogenic Wastes	Hospital Used Bandages, and Dressings
529	Explosive Wastes	Red Mud from Munitions Manufacture
531	Contaminated Rags	Cleanup Materials
532	Equipment and/or Containers Contaminated with Pesticides	Empty Pesticides Cans

NOTES TO APPENDIX A

a	UCD 121	May contain zinc or aluminum which can precipitate at pH<11. Most streams are assumed to contain other metals.
b	UCD 141	Ultrafiltration may be applicable, if surfactants have been used in tank cleaning operations. This is not thought to be typical of wastes in this category.
c	UCD 143	Some wastes will require reduction and others, oxidation. The waste streams that are treatable by chemical reduction and oxidation are assumed to be evenly divided in all system options.
d	UCD 145	These brine solutions are likely to contain suspended solids or precipitates.
e	UCD 146	Although cyanide solutions could be incinerated to reduce the hazardous character of the waste, incineration is not considered an applicable treatment for three reasons: 1. The waste stream is primarily water (aqueous waste) and aqueous streams are not normally incinerated when alternative treatment technologies exist. 2. If metals are present, these may be released to the environment through the incinerator emissions. 3. The incinerator is designed and operated to burn organics, not cyanides; extra care in operation and handling of wastes would be required to ensure safe operation.
f	UCD 165	Since most catalyst will be metals on inorganic substrates, this stream is not considered incinerable.
g	UCD 211, 212, 214, & 215:	Assumed to have suspended, not dissolved, metals.
h	UCD 223:	These are assumed to contain only small quantities of suspended solids.
i	UCD 225 & 226:	Average organic content is assumed to be 1%.
j	UCD 227 & 228:	These aqueous/organic solutions are assumed to have an average organic content of 10-20%.
k	UCD 244:	Assumed to be waste film, paper, etc. from photoprocessing. Inorganic chemicals from processing that contain silver would be included in UCD 141 (Aqueous solutions with heavy metals).

l UCD 252: Although these wastes can be incinerated, land disposal is the currently accepted means of disposal of tannery sludge wastes; if incinerated chromium may be oxidized to Cr (VI).

m UCD 416, 454, 455, & 447: These sludges are assumed to contain 25% or more suspended solids. Because of their high initial solids content, they are not normally centrifuged.

n UCD 444: Although this stream could be incinerated, it is mostly non-burnable solids and is not incinerated. It is assumed that cyanide in these sludges are complexed and, therefore, solidifiable. If wastes contain free cyanides, they are treated as UCD 146 (Solution Containing Cyanides).

o UCD 523: This is assumed to be aqueous/organic mixtures and is likely to contain high levels of suspended solids. Tank bottom sediments from cleaning tanks that do not contain organics are assumed to be in UCDs 141 & 142 (Aqueous solutions with metals).

APPENDIX B

UCD CATEGORIES BY WASTE CLASS*

APPENDIX B

UCD CATEGORIES BY WASTE CLASS*

CLASS 1: ORGANIC SLUDGES AND STILL BOTTOMS

247	Halogenated Still Bottoms	Spent Solvent or Waste Oil Recovery	300
248	Non-Halogenated Still Bottoms	Solvent Recovery Operations	1,200
252	Solid or Sludge Tannery Wastes	Leather Shavings with Chrome	3,000
257	Phenolic Wastes	Phenolic Oil. Toluene Diisocyanate Residue	100
261	Polymeric Resin	Polyester, Urethane, Etc.	3,000
263	Other Polymeric Wastes	Kettle Bottoms, Thermoplastic Resins	2,000
446	Degreasing Sludge	Grease and Oily Soil Containing Trichloroethane (TCE)	1,000
523	Tank Bottom Sediments		1,000
		CLASS 1 TOTAL	11,600

CLASS 2: SOLVENTS AND ORGANIC SOLUTIONS

211	Halogenated Solvents with Heavy Metals	Methylene Chloride, 1,1,1 Trichloroethylene Used for Metal Cleaning	700
212	Halogenated Solvents with Other Metals	Surface Cleaning and Degreasing Solvents	100
213	Other Halogenated Solvents	Freon with Other Solvents Used in Chemical Processing	500
214	Non-Halogenated Solvents with Heavy Metals	Toluene, Benzene, Xylene Contaminated with Catalysts	600
215	Non-Halogenated Solvents with Other Metals	Acetone, Methlisobutylketone (MIBK) used in Paint and Varnish Formulation	300

* Waste quantity data was provided by OWMC ("Waste Profile," November 1984)

CLASS 2: SOLVENTS AND ORGANIC SOLUTIONS (continued)

216	Other Non-Halogenated Solvents	Methylethylketone and Other Solvents Contaminated with Dirt	300
217	Unspecified Solvents	Alcohols and Mixtures of Solvents	1,000
221	Organic Liquids with Metals and Halogens Only	Dyes	50
222	Organic Liquids with Halogens Only	Chloroform, Carbon Tetrachloride	5
223	Organic Liquids with Metals Only	Nickelcarbonyl, Methyl Mercury	20
224	Other Organic Liquids	Creosote and Other Poly Aromatic Hydrocarbons	200
		CLASS 2 TOTAL	3,775

CLASS 3: OILS AND GREASES

281	Waste Oil and Mixed Oil	Used Automotive Oil, Hydraulic Oil, Cutting Oil May Contain Solvents or Metals	1,000
		CLASS 3 TOTAL	1,000

CLASS 4: OILS AND WATER MIXTURES

283	Oily Mud, Sediment and Water	Crude Oil Tanker Cleaning	4,000
289	Oily Wastes with Water	Emulsions, Cleanup Water Garages, Cooling Water	3,000
		CLASS 4 TOTAL	7,000

CLASS 5: ORGANIC AND OILY RESIDUALS

264	Thermoset Wastes	Urea-Formaldehyde and Thermoset Wastes	10
282	Oily Tank Bottoms	Crude Oil or Sludge from Storage	500

CLASS 5: ORGANIC AND OILY RESIDUALS (continued)

284	Oily Acidic Solids	Solids from Emulsion Breaking and Re-refining	2,000
285	Oily Alkaline Solids	Refining Solids	10
286	Oil/Water Separator Sludge	Oil Cooled Heavy Inorganics	300
288	Oily Wastes with Heavy Contaminants	Steel Rolling Mill Sludges and Mill Scale	1,000
289	(moved to Class 4)		
447	Tetraethyl Lead Sludge	Tank Bottoms	5
		CLASS 5 TOTAL	3,825

CLASS 6A: METAL SOLUTIONS AND RESIDUALS

111	Acidic Solution with Heavy Metals	Pickle Liquor Rinse Water	8,000
112	Acidic Solution with Other	Demineralizer Regenerent	4,000
113	Other Acidic Solutions	Boiler Stack Scrubber Water with Dilute Carbonic Acid (H_2CO_3)	3,000
121	Alkaline Solution with Heavy Metals	Rinse Waters from Surface Cleaning of Metals	10,000
122	Alkaline Solution with Other Metals	Demineralizer regenerent	500
123	Other Alkaline Solutions	Cleanup Water from Lime or Cement Kiln	3,700
131	Metal Finishing Solutions Acid	Ammonia Based, Containing Copper, Tin, Lead, or Cadium	1,500
132	Metal Finishing solutions, Alkaline	Contains Strong Complexing Agent and Copper, Tin, Lead and/or Cadmium	500
133	Spent Pickle Liquor from Ferrous and Non Ferrous Metals	Strong Acids with Iron, Fluoride, Hydrochloric Acid (HCL), Sulfuric Acid (H_2SO_4), Nitric Acid (HNO_3)	2,000

CLASS 6A: METAL SOLUTIONS AND RESIDUALS (continued)

141	Aqueous Solutions with Heavy Metals	Cleaning Solutions from Tanks, Trucks, or Railroad Tankers	10,000
142	Aqueous Solutions with Other Metals	Rinse Water from Heat Treating Salt Baths, Contain Barium, Aluminum	7,000
143	(moved to Class 10)		
145*	Brine	Salt Solutions After Neutralization or Chlor/Alkali Production	10
244	Photochemical Waste	Most Solutions Non-Toxic Except Those with Silver	500
251	Tannery Wastes - Liquid	Solutions with Hexavalent Chromium	2,000
		CLASS 6A TOTAL	52,710

CLASS 6B: METAL SOLUTIONS AND RESIDUALS

431	Heavy Metal Sludge	Similar to that in 111, 113,121,123,132,133,141	15,000
433	Other Metal Sludges	Ferric Chloride, Aluminum Oxide, etc.	2,000
445	Plating or Metal Finishing Sludge	Derived Mostly from 131, 132, 133	2,000
523	Tank Bottom Sediments (also in Class 1)		
		CLASS 6B TOTAL	19,000

CLASS 7: MISCELLANEOUS CHEMICALS AND PRODUCTS

243	Pharmaceuticals and Wastes	Off-Spec. Drugs, Cleanup Includes Items such as Vitamins	200

* Omitted from OWMC classification

CLASS 7: MISCELLANEOUS CHEMICALS AND PRODUCTS (continued)

245	Off-Spec or Aged Organics	Can Include Solids or Liquids. Generally in Containers	500
416	Ink Sludge	Sludge Could Contain Solvents, and Lead. Cesium, Chromium	200
513	Laboratory Waste Chemicals	Partially Full Small Containers	200
		CLASS 7 TOTAL	1,100

CLASS 8: PAINT AND ORGANIC RESIDUALS

254	Adhesives or Glue	Waste Glues Mostly Aqueous. Some with Phenols	500
258	Waste Tar and Residues		2,200
262	Latex Wastes	Cleanup Water, Paint, Latex and Acrylic Resins	500
454	Paint Sludge	Drum Bottoms, Spills, Cleanup, etc.	2,000
455	Paint Sludge Without Heavy Metals	Mostly Latex, Similar to 272	500
		CLASS 8 TOTAL	5,700

CLASS 9: AQUEOUS ORGANIC SOLUTIONS

225	Aqueous Solution with Non-Halogenated Residues Less Less Than 10%	Laboratory Mixtures	1,500
226	Aqueous Solutions with Halogenaged Residues Less Than 10%	Waste or Rinse Waters Degreasing	10
227	Aqueous Solution with Non-Halogenated Organic Residue Greater Than 10%	Laboratory Mixtures	500
228	Aqueous Solution with Halogenated Organic Residue Greater Than 10%	Wash or Rinse Waters After Degreasing	10
		CLASS 9 TOTAL	2,020

CLASS 10: ANION COMPLEXES

146	Solutions Containing Cyanide	Plating Baths	600
147	Solutions Containing Sulfides	Plating Baths	10
444	Cyanide Bearing Sludge	Pot Liners from Aluminum Reduction and Scrubber Sludge from Blast Furnaces	400
143	Aqueous Solutions With Reactive Anions	Bleaching Lolutions Sulfate, Chlorite, Flouride, Bromate	2,500
		CLASS 10 TOTAL	3,510

CLASS 11: SLUDGES AND INORGANIC RESIDUALS

151	Inorganic Solids	Foundry Sand with Phenolics	10,000
165	Spent Catalyst	Maybe Carbon or Metal	200
167	Other Inorganic Waste	Ash and Construction Residue	3,000
518	Dust Collector Wastes	Dry Lime from Dust Control Baghouse	2,000
152	Inorganic Solid Chemicals	Aged or Off Spec. Chemicals Including Lime, Caustic Soda and Partial Containers of Laboratory Size	2,000
417	Alum and Gypsum Sludges	Waste Water Phospate. Removal Sludge	100
441	Lime Sludges	From Treatment of Acids and Similar to 431 and Derived from 111, 113, 121, 123, 131, 132, 133, 141	15,000
443	Sulfur Sludge	Desulfurization of Flue Gas Non-reactive but Very Low Bearing Strength	10
		CLASS 11 TOTAL	32,310

CLASS 12: PESTICIDE AND HERBICIDE WASTE

241	Pesticides and Wastes	Partial Containers, Tank Washings, Off Spec. Product, etc.	150
532	Equipment and/or Containers Contaminated With Pesticides	Empty Pesticide Cans	50
		CLASS 12 TOTAL	200

CLASS 13: PCB WASTES

242	PCB Oils and High Strength (over 500 ppm)	From Transformers and Capacitors	40
		CLASS 13 TOTAL	40

CLASS 14: CLEAN-UP RESIDUALS

509	Gas Cylinders		5
512	Spill Cleanup	Oil/Soil Mixture	700
521	Spent Cartridge Filters	Air Cleaning Filters on Ventilation System	700
528	Pathogenic Wastes	Used Bandages, Dressings	700
531	Contaminated Rags	Cleanup Materials	700
		CLASS 14 TOTAL	2,805
		GRAND TOTAL	146,495

APPENDIX C

UPDATE TO GENERIC PROCESS TECHNOLOGIES STUDIES

APPENDIX C

UPDATE TO GENERIC PROCESS TECHNOLOGIES STUDIES

This appendix updates the proven technologies described in the "Generic Process Technologies Studies" by Procter & Redfern (1982).(1) It follows the same general organization as that report; individual technologies have been divided into five categories for purposes of discussion--biological treatment, physical/chemical treatment, thermal processing, solidification/stabilization, and ultimate disposal.

The following nine topics were discussed in Proctor & Redfern for each technology:

- Process description.
- Waste input.
- Effluents and residuals.
- Implementation, reliability.
- Process applications.
- Economic considerations.
- Energy requirements.
- Resource recovery.
- Environmental factors.

Our review of the generic* technologies showed that the discussions in Proctor & Redfern are still basically correct since the state-of-the-art has not changed significantly since 1982. We do note though that cost estimates are out of date, certain emerging technologies are not covered, and there are errors in the matching of wastes to technologies that can treat these wastes in some cases.

GENERIC PROCESS TECHNOLOGIES

Table C.1 lists the generic treatment and disposal technologies. They have been divided into proven and unproven categories as defined by OWMC; i.e., a proven technology is one that has been "commercially demonstrated to have performed reliably for a period of at least 12 months on a scale and in a manner comparable with that required for the OWMC facility." The technologies marked with an asterisk (*) in Table C.1 were not included in the 1982 Proctor & Redfern report.(1)

In the remainder of this appendix, the individual proven generic technologies within each process group are discussed. To assure complete understanding of what is meant by each specific technology in this study, brief descriptions with block flow diagrams are included.

The cost information for each technology is based on a system with sufficient capacity to handle all the waste expected to be received by OWMC that is treatable by that particular technology. The purpose of the cost estimate is to compare technologies in the technology-evaluation tasks in Section 2 of this assignment.

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* Generic technologies are normally described by the major reaction or separation taking place and the major piece of process equipment. Most generic processes have one or more proprietary modifications. Even though these proprietary modifications may significantly alter the performance of the technology, when compared to the generic technology from which it is derived, only generic technologies are discussed within the scope of this overview.

TABLE C.1

AVAILABLE GENERIC TREATMENT/DISPOSAL TECHNOLOGIES

Proven Technologies	Unproven Technologies
• Biological Treatment Processes	
Activated Sludge Activated Sludge/Powdered Activated Carbon Treatment Activated Sludge Using Pure Oxygen Anaerobic Digestion Fluidized Bed Contactor Land Treatment Rotating Biological Contactor Trickling Filter Waste Stabilization Pond	Composting Enzyme Treatment/Mutant or Adapted Microorganisms *Sequencing Batch Reactor
• Physical Separation Processes	
Air Stripping Carbon Adsorption Centrifugation Dissolved Air Flotation Electrodialysis Emulsion Breaking Evaporation Filtration Flocculation/Sedimentation Resin Adsorption Reverse Osmosis Solvent Extraction Steam Stripping Ultrafiltration	*Electrophoresis *Freeze Drying Liquid Ion Exchange *Magnetic Separation *Supercritical Fluid Extraction *Suspension Freezing *Zone Refining
• Chemical Treatment Processes	
Chemical Reduction Chemical Oxidation Dehalogenation Ion Exchange Neutralization Precipitation Wet Air Oxidation	*Chlorinolysis *Cavitation Hydrolysis *Supercritical Water Oxidation UV/Ozonation UV/Hydrogen Peroxide *Vertical Tube Wet Air Oxidation

TABLE C.1 (continued)

Proven Technologies	Unproven Technologies
• Thermal Treatment Processes	*Calcination
	*Catalysis
Cement Kiln Incineration	*Fluid Wall Reactor
Fluidized Bed Incineration	*Infrared Electric Furnace
Liquid Injection Incineration	Molten Salt Incineration
Multiple Hearth Incineration	*Molten Glass Incineration
*Pyrolysis	Plasma Arc
Rotary Kiln Incineration	Microwave Plasma Discharge
• Solidification/Stabilization Processes	
Cement Based Processes	Organic Polymer Stabilization
Lime Based Processes	Thermoplastic Stabilization
Silicate Based Processes	
• Disposal Processes	
Deep Well Injection	RUMOD (underground rock storage)
Geologic Isolation	
Engineered Landfill	
Warehouse Storage	

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* Not included in Reference (1).

Therefore, the cost estimates are for the incremental operating costs only. Incremental costs are those incurred if this technology were added to an operating facility; no costs for plant management or for receiving, analyzing, and storing wastes are included. No capital recovery, depreciation, interest or tax is included in the operating costs. All costs are expressed in December, 1985 Canadian dollars.

BIOLOGICAL PROCESSES

ACTIVATED SLUDGE (1,2,4,6,7,8)

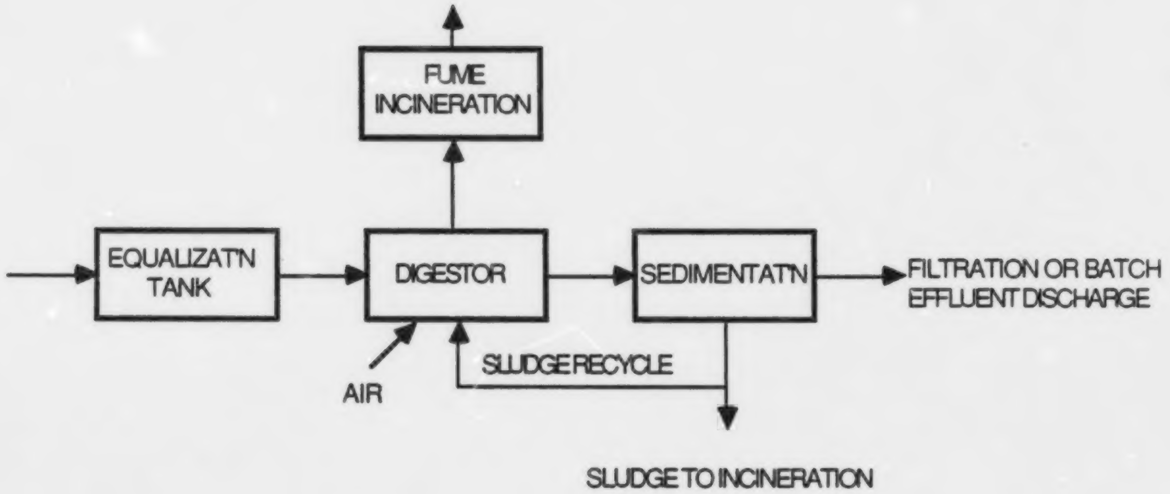
Process Description

The process is used commonly for both domestic and industrial wastewaters. The equalization and activated sludge tanks may be open to the atmosphere or covered and vented; for this analysis, with feed rates of only about 2,000 tonne per year, closed tank indoor systems were assumed. Air is introduced through a system of diffusers or surface aerators. The "activated sludge" is the aerobic suspended media. There is typically no external heat source and the reaction is generally less efficient in colder climates, if out-of-doors. Sedimentation allows the reuse of the activated sludge by recycling part of the thickened underflow back to the process tank. Filtration is normally required to reduce suspended solid content in the effluent to an acceptable level for discharge to surface waters. For this analysis, it is assumed that the vent gas from the process tank is ducted to an incinerator. A block flow diagram is given in Figure C.1.

Normal Operations

As indicated by the block flow diagram in Figure C.1, discharges from the activated sludge process include excess biomass sludge, an aqueous stream that contains residual organics (including hazardous and toxic organics at levels of 1 mg/l or less),[1] salts and suspended solids, and a vent stream that may contain volatile organics.

FIGURE C.1: ACTIVATED SLUDGE



Both the aqueous stream and the biomass can be held in a tank or other form of containment and analyzed to assess the need for further treatment prior to any discharge to the environment. No organic emissions from the activated sludge tank go directly to the environment. Even though emissions from the activated sludge tank are continuous they can be directed to an incinerator or passed through a carbon adsorption.

Where influent wastes contain high concentrations of nitrogen, the effluent stream may require treatment to remove ammonia or nitrate.(1)

Operators of an activated sludge process would require no special personal protective equipment.

Abnormal Events

Releases to the work place environment could occur in the event of tank rupture or valve failure. The system can be diked or otherwise contained so that the resultant spills are captured for subsequent treatment. Failure of the emission control system could lead to exposure of workers to small concentrations of volatile organics. There is also the possibility of a small volume air release to the surrounding community, but there is very little potential human health or environmental damage because the wastes amenable to biological treatment are very dilute and because further dilution will occur as the release moves from the treatment tank across the buffer zone of the facility to points of impingement.

Types of Wastes Treatable (input flexibility)

Only wastes in UCD category 225 (aqueous solutions with non-halogenated residue less than 10%) are potentially treatable by an activated sludge process. Furthermore, all wastes even in these categories may not be amenable to activated sludge treatment because activated sludge treatment is generally applicable to aqueous solutions with less than 1% organics. Other restrictions are COD less than 50,000 mg/L, phenols less than 10 mg/L, heavy metals less than 5 mg/L and pH between 7 and 8. Industrial wastes deficient in such nutrients as nitrogen and phosphorus may require supplementation to maintain a healthy population of microorganisms.(1)

Operational Flexibility (start-up and shut down as needed)

An activated sludge system must be operated continuously to maintain the active population of microorganisms that is required for effective treatment. If a steady feed of organics is not maintained, the microorganisms starve.

Unscheduled Downtime (operational reliability)

According to a spokesman at a facility contacted as part of this work, unscheduled downtime for an activated sludge system is in the range of 5%-20%, on an annual basis. The facility contacted had been in operation for four years and received waste primarily from the petrochemical industry. The activated sludge system at this facility has a design capacity of about 1,000 cubic meters per day and processes about 200 cubic meters per day. Experience has been that process upsets occur between 3 and 12 times per year, resulting in a significant kill of the biomass. On such occasions the tanks are drained into a storage basin, the pH and waste load are adjusted, and the activated sludge tanks are reseeded with microorganisms. Reestablishment of full capacity for biological treatment takes from one day to one week.

Ease of Operation and Monitoring (technical reliability)

An activated sludge system is mechanically very simple to operate, but sensitive to pH, flow, dissolved oxygen, temperature and shock loading.(1) All of these must be very closely controlled. Continuous monitoring of key parameters is possible with operator supported adjustment of operating conditions.

Cost

For treatment of all treatable, incoming, OWMC wastes, a 2,000 tonnes per year system is required. For this small system, treatment costs would be approximately $15 per tonne of incoming waste.

ACTIVATED SLUDGE USING PURE OXYGEN (1,2,4,6,7,8)

This technology differs from conventional activated sludge treatment only in that pure oxygen is used instead of air. This increases the complexity of the system somewhat, but can result in more efficient and effective biodegradation. Otherwise, the description for conventional activated sludge applies.

ANAEROBIC DIGESTION (1,2,4,6-10)

Process Description

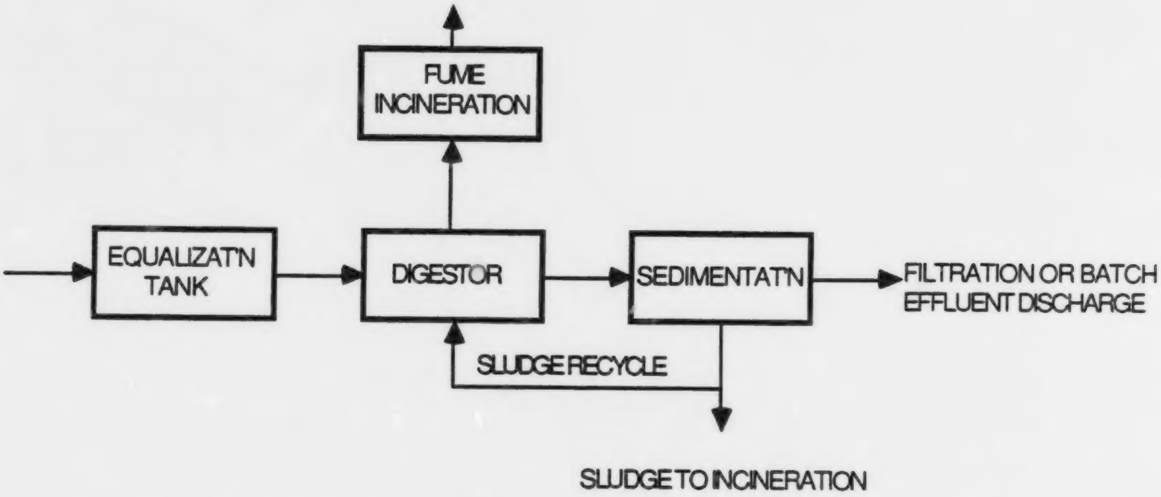
Anaerobic digestion is an anaerobic suspended media biological process which produces methane as a gaseous byproduct. Sulfates and nitrates can also be removed from wastewater by anaerobic digestion. The biological process takes place in a closed tank, which often requires an external heat source to maintain a constant temperature. A block flow diagram is shown in Figure C.2.

Normal Operations

Under normal operating conditions there are no direct discharges to the environment from an anaerobic digestion system. The sludge residual and aqueous effluent are collected for transfer to further treatment or, in the case of the aqueous stream, for release. The methane-rich gas is directed to an incinerator.

Special care and precautions must be practiced to eliminate the potential for personnel asphyxiation or gas explosion (due to air infiltration into methane-rich enclosure) when equipment is opened.

FIGURE C.2: ANAEROBIC DIGESTION



Abnormal Events

Spills and leaks from an anaerobic digestor can be contained to prevent worker or community exposure, in the same manner as for activated sludge (see page C-6). Accidental release of gases would expose workers to volatile organics and possibly hydrogen sulfide for the brief period before they were able to put on respirators. By the time off gases leave the property, they will have been diluted to very low concentrations. Although there should be no effect on community health there may be odours, since some compounds formed during the process (e.g., reduced sulfur species) have noticeable odours at concentrations below their thresholds for toxicity.

Types of Wastes Treatable (input flexibility)

Anaerobic digestion is applicable to more concentrated aqueous solutions of organics than is activated sludge treatment. Wastes in UCD category 225 are potentially treatable. The system is sensitive to shock loading, and may be inhibited by heavy metals, high concentrations of alkali, metal ions, and certain pesticides.(1)

Operational Flexibility (start up and shut down as needed)

Continuous operation is required to maintain a healthy colony of microorganisms for biodegradation. Temperature and pH must be closely controlled.(1) As for activated sludge, this is normally a continuous process.

Unscheduled Downtime (operational reliability)

Due to the sensitivity of the system to process parameters, moderate unscheduled downtime (5-20%) can be expected.

Ease of Operation and Monitoring (technical reliability)

Key parameters (pH, temperature, flow) can be monitored continuously with operator adjustment of processing conditions.

Costs

Operating costs for an anaerobic digestor with a capacity of about 2,000 tonnes per year are of the order of $15 per tonne.

FLUIDIZED BED BIOLOGICAL CONTACTOR (1)

Process Description

The fluidized contactor is a cross between the fixed and suspended media concept. A closed vessel contains biomass-covered sand or similar granular particles suspended in an upward flow of wastewater. A block flow diagram is shown in Figure C.3.

Normal Operations

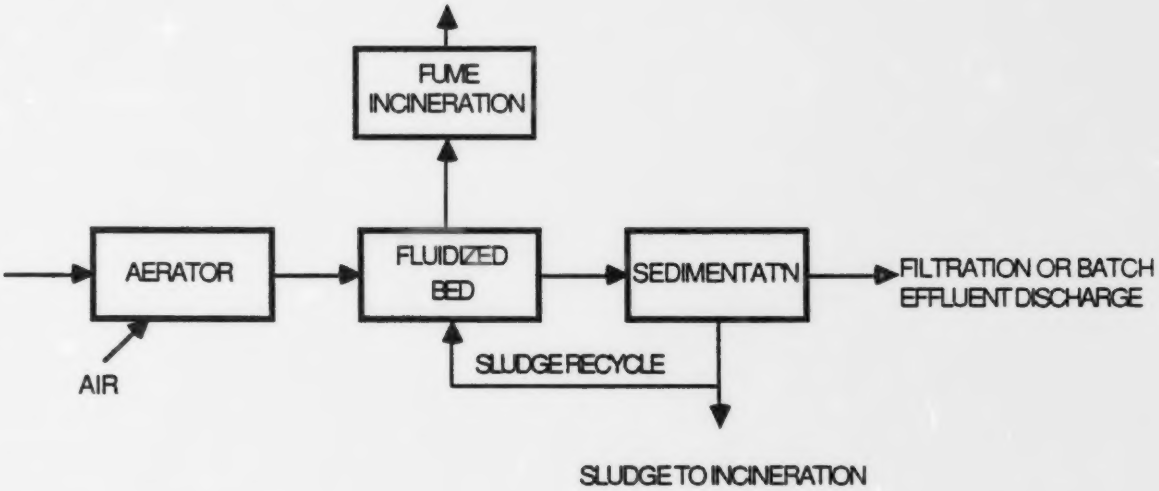
The fluidized bed contactor can be operated so that there are no uncontained releases during normal operations. Volatile organics released in the pre-aeration step can be captured in a carbon adsorption column, condensed, or incinerated. Sludge can be contained for subsequent incineration. The aqueous effluent can be contained for analysis prior to discharge or further treatment.

Personnel would not have to wear special protective clothing during normal operations.

Abnormal Events

On-site personnel may be exposed to volatile organics in the event of failure of the control system for treating gaseous emissions from the pre-aeration step. Concentrations in the air will

FIGURE C.3: FLUIDIZED BED BIOLOGICAL CONTACTOR



necessarily be low because the feed solution must be dilute to sustain biological activity. Any air releases at the site are unlikely to damage the surrounding environment or harm the neighboring population due to the buffer zone around the facility.

Types of Wastes Treatable (input flexibility)

Only some wastes from UCD category 225 are potentially treatable, with the same caveats described for activated sludge treatment.

Operational Flexibility (start up and shut down as needed)

The process must be operated continuously to maintain a healthy population of microorganisms for biodegradation, as well as to maintain the fluidization of the bed.

Unscheduled Downtime (operational reliability)

Dissolved oxygen in the incoming stream to the fluidized bed, flow rate, temperature, pH, heavy metal content and total dissolved organics in the input to the fluidized bed must all be closely controlled to insure optimum biological activity. A moderate (5%-20%) amount of unscheduled downtime can therefore be expected.

Ease of Operation and Monitoring (technical reliability)

A fluidized bed contactor is more complex operationally than an activated sludge system, and varying input loads may make it difficult to attain steady state in the reactor.(1) However, key parameters can be monitored continuously and adjustments made by the operator.

Costs

For a 2,000 tonne per year fluidized bed contractor system, operating costs would be approximately $15 per tonne.

LAND TREATMENT (1,2,4,5,8,11-17)

Process Description

Land treatment utilizes soil as the medium which supports microbial biomass. Wastes are tilled into the upper 15-20 centimeters of the soil. A cover crop may be planted. In a well-designed land treatment system, hazardous components of wastes are either biodegraded by naturally-occurring microorganisms in the soil; transformed physically, chemically, or biologically; immobilized by adsorption to soil particles; or volatilized. Land treatment is based on the premise that soils have a natural assimilative capacity for each type of contaminant, soil condition, and climate. Therefore, if wastes are applied at rates and concentrations that do not exceed that natural assimilative capacity, the land may not be preempted from certain future uses. Land treatment is shown in Figure C.4.

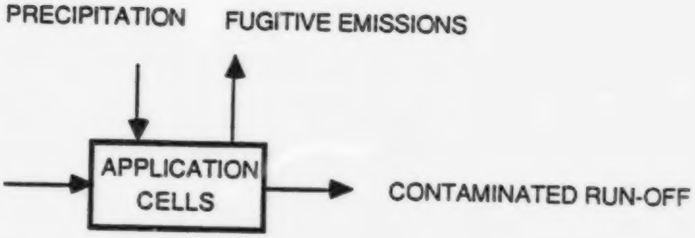
Normal Operations

Land treatment does result in the release of volatile organics to the atmosphere. The routine use of respirators during waste application should minimize the problem of exposing on-site personnel, however. Other discharges, such as leachate and runoff, require periodic monitoring.

Abnormal Events

The spreading of wastes may lead to odours. They can be controlled by subsurface injection and should not persist if aerobic conditions exist.(1) A flood exceeding that for which the facility was designed, could result in contamination of the surrounding environment and in exposure of the off-site population.

FIGURE C.4: LAND APPLICATION



Types of Waste Treatable (input flexibility)

Land treatment is used on organic wastes amenable to biodegradation. These include some wastes from UCD categories 248, 252, 282, 283, 284, 285, 286 and 523. Land treatment is not easily upset by minor waste constituents. However, the rate of waste application should be controlled and limited to prevent the accumulation of unacceptable concentrations of toxic inorganics or refractory organics in the soil.(1) Volatile and leachable wastes may not be acceptable.(1)

Operational Flexibility (start up and shut-down as needed)

Unlike other biological treatment processes, land treatment systems are operated in a batch mode, allowing flexibility in the scheduling of waste application.

Unscheduled Downtime (operational reliability)

Land treatment has low (<5%) unscheduled downtime due to the simplicity of the operation during the seasons of the year when operation is normally possible. The only equipment used, aside from that used to apply the waste, are the monitoring devices. However, provision should be made for storage of wastes (or alternative treatment) during the seasons when the ground is frozen.

Ease of Operation and Monitoring (technical reliability)

Land treatment is one of the simplest biological treatment methods operationally and the equipment employed in the process is well established.(1) Parameters requiring monitoring include leachate and runoff as well as air emissions. One also needs to monitor the disappearance of waste constituents from the zone of incorporation and to adjust rates of application of wastes so that the soils assimilative capacity is not exceeded. While the physical operations are simple, management to assure complete degradation, transformation or immobilization is moderately complex.

Cost

A land treatment operation with a capacity of 11,000 tonnes per year has an operating cost of about $30 per tonne.

ACTIVATED SLUDGE/POWDERED ACTIVATED CARBON (1,11)

Powdered activated carbon augments conventional activated sludge with the physical treatment capabilities of activated carbon. The technology has been used to treat industrial and combined industrial/domestic waste waters which contain small quantities of wastes that are normally too difficult to treat by biological processes alone, such as traces of chlorinated solvent residues. Tanks can be closed or open to the atmosphere and oxygen is supplied through a system of compressed air diffusers. No external heat is supplied. As is the case for all biological processes, the reaction is generally less efficient in cold climates. A block flow diagram is shown in Figure C.5.

Normal Operations

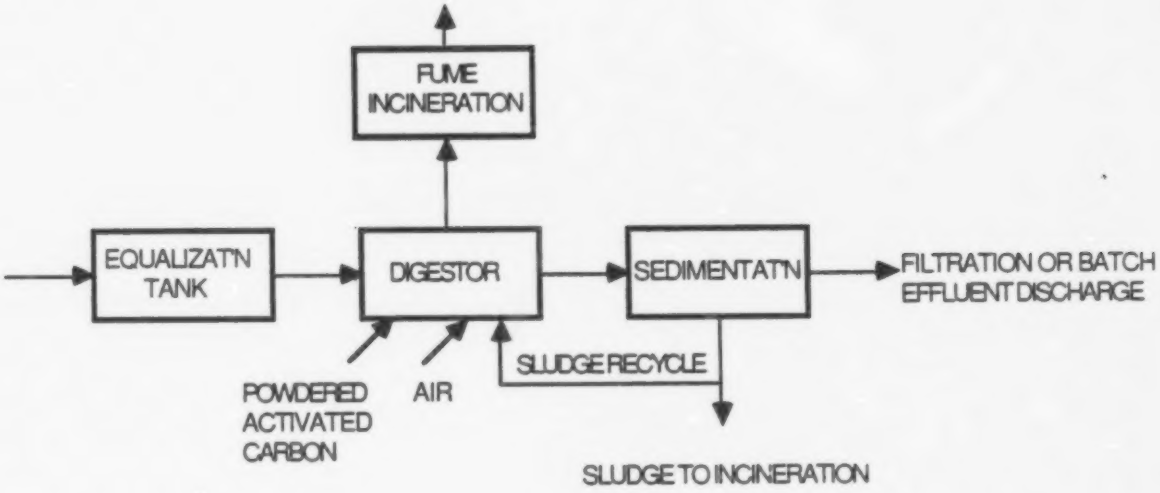
Activated sludge/powdered activated carbon results in no direct emissions to the environment under normal operating conditions. Volatile organics released during the aeration process are incinerated in the technology assumed in this analysis. Sludge and spent powdered carbon resulting from the process are incinerated. In larger systems the activated carbon could be regenerated or recycled.

The powdered activated carbon must be handled carefully to avoid excessive black dust in the plant surroundings.(1) No special personal protective equipment is required.

Abnormal Events

In the event of an accident, on-site personnel may be exposed to uncontrolled gaseous emissions of volatile organics prior to emergency

FIGURE C.5: ACTIVATED SLUDGE/ POWDERED ACTIVATED CARBON



response. Small volume air releases are possible off-site, although natural dispersion will reduce the concentration of any release before reaching the property boundary.

Types of Wastes Treatable (input flexibility)

Activated sludge/powdered activated carbon can be used to treat more concentrated aqueous organic waste than conventional activated sludge processes. These wastes include some of the wastes from UCD categories 225 and 226.

Operational Flexibility (start up and shut-down as needed)

Activated sludge/powdered activated carbon systems must be operated continuously to maintain effective and efficient biodegradation.

Unscheduled Downtime (operational reliability)

Activated sludge/powdered activated carbon systems are more resistant to upset by minor constituents than normal activated sludge processes since materials toxic to the microorganisms may be adsorbed by the activated carbon.(1) The greater ability of activated carbon systems to withstand shock organic loads and hydraulic overloads explains why these systems have less unscheduled downtime than conventional activated sludge systems, i.e., less than 5%.

Ease of Operation and Monitoring (technical reliability)

Activated sludge/powdered activated carbon systems are simple in operation, as is activated sludge. Periodic monitoring of COD, flow and pH are required. If the activated carbon is regenerated thermally, the stripped gases would have to be condensed or incinerated to control potential contamination of workplace and ambient air.

Cost

Operating cost for activated sludge/powdered activated carbon with a capacity of 2,000 tonnes per year would be roughly $20 per tonne.

ROTATING BIOLOGICAL CONTACTOR (1,4,8)

Process Description

Rotating biological contactors consist of multiple, large wheels that are half submerged in wastewater. As the wheels rotate, the biomass on the wheels is alternately exposed to wastewater and air. This provides an environment conducive to biological growth. A rotating biological contactor system is shown in Figure C.6.

Normal Operations

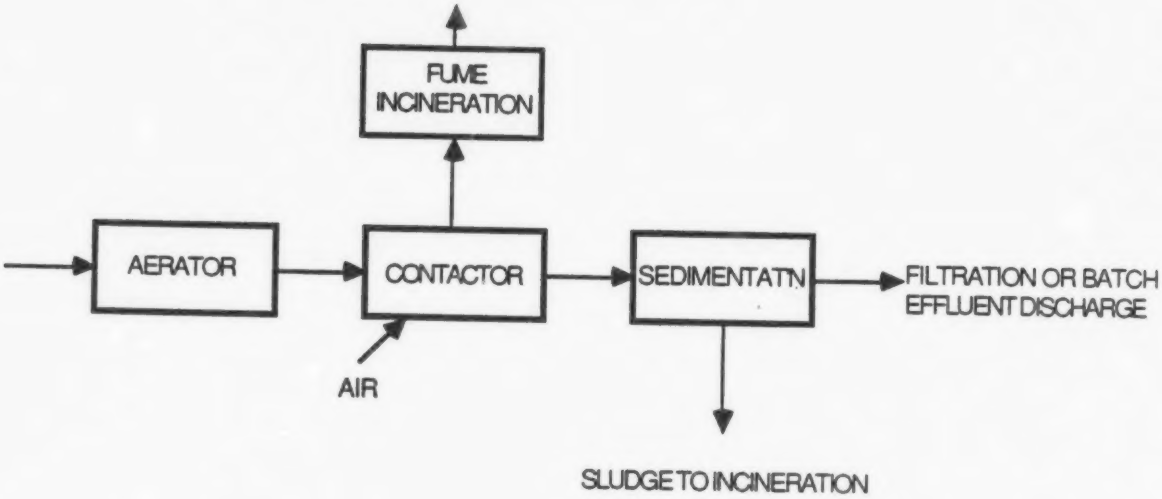
Under normal operations, no uncontrolled releases to the environment occur with rotating biological contactors. Offgases from the units (which are covered) can be incinerated and the sludge that results can be dewatered and incinerated.

No special personal protective equipment is required.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions of volatile organics prior to emergency response in the event of a failure of the offgas incinerator or pollution control device. Small volumes of gaseous emissions may reach off-site. However, exposure to off-site population will be minimized by dilution, the buffer zone and emergency response on-site.

FIGURE C.6: ROTATING BIOLOGICAL CONTACTOR



Types of Waste Treatable (input flexibility)

Rotating biological contactors can be used to treat some wastes in UCD category 225. Waste must have COD of less than 50,000 mg/L , phenol content of less than 10 mg/L, heavy metals of less than 5 mg/L and pH of between 7 and 8.

Operational Flexibility (start up and shut down as needed)

Rotating biological contactors must be operated continuously to maintain an active population of microorganisms. The biomass attached to the disks may become anaerobic or dry out if the system is shut-down at night or on weekends.(1)

Unscheduled Downtime (operational reliability)

A moderate amount of unscheduled downtime (5-20%) can be expected with rotating biological contactors. However, this system is less easily upset by fluctuations in hydraulic and organic shock loads than activated sludge systems and more resistant to toxic shock loads as well because of the large quantity of biomass in the system.(1) Because most rotating biological contactors have been installed during the last 10 years, there is little long-term operating experience.(1)

Ease of Operation and Monitoring (technical reliability)

Rotating biological contactors are more complex in operation than activated sludge systems because of the maintenance requirements for the fixed media on the rotating contactor. However, compared with activated sludge systems, they require less attention during operation and fewer process decisions by the operator(1) as long as the feed is reasonably steady and constant. Periodic monitoring for COD is necessary, as well as for pH, flow, and temperature.

Cost

For a rotating biological contactor system with a capacity of 2,000 tonnes per year, an operating cost of roughly $15 per tonne can be expected.

TRICKLING FILTER (1,2,4,6,8)

Process Description

Trickling filters consist of biomass-covered stones, wood, or synthetic media. The wastewater is sparged over the top of the media while air is vented up from below. The result is a thin film of contaminated water exposed to both air and biomass. No external heat source is supplied and the facilities must be covered in cold climates. A trickling filter is shown in Figure C.7.

Normal Operations

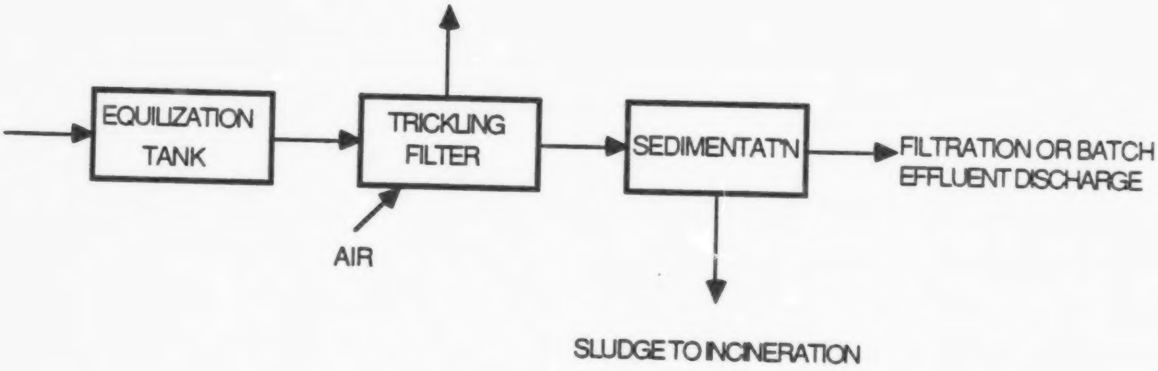
No direct discharges to the environment should occur from trickling filters under normal operating conditions. Air that is vented from the system can be incinerated or passed through activated carbon to adsorb volatiles. Sludge from the process can be dewatered and also incinerated. Fly larvae are part of the food chain that exist in the filters and adult flies can be a nuisance in the surrounding area at certain times of the year.(1)

No special personal protective equipment is required.

Abnormal Events

Uncontrolled gaseous emissions may occur if wastes containing volatile organics are applied and the air treatment system fails, exposing on-site personnel to volatiles prior to emergency response. Off-site exposure should not occur due to dilution in the buffer zone and emergency response on-site. Anaerobic conditions may develop in

FIGURE C.7: TRICKLING FILTER



parts of the filters at high loading rates, which may cause odour problems.(1)

Types of Wastes Treatable (input flexibility)

Trickling filters can handle some wastes in UCD waste category 225. These wastes must have a COD of less than 50,000 mg/l, phenols less than 10 mg/l, heavy metals less than 5 mg/l, and a pH of between 7 and 8.

Operational Flexibility (start up and shut-down as needed)

Trickling filters must be operated continuously to maintain an active population of microorganisms required for effective treatment.

Unscheduled Downtime (operational reliability)

Trickling filters are sensitive to pH, flow, temperature and toxic constituents. Consequently, a moderate (5%-20%) amount of unscheduled downtime can be expected due to uncontrollable fluctuations as feed composition changes.

Ease of Operation and Monitoring (technical reliability)

Trickling filters are complex in operation compared to activated sludge treatment. Periodic monitoring for COD is required and temperature must be closely controlled.

Cost

Trickling filters systems with a capacity of 2,000 tonnes per year would have an operating cost of roughly $15 per tonne.

WASTE STABILIZATION POND (1,2,4,8)

Process Description

Stabilization ponds generally consist of a series of ponds of different depth which facilitate the growth of a variety of aerobic and anaerobic organisms. Ponds are land-intensive, require little energy input, and often generate less sludge (compared to activated sludge), since anaerobic processes, as would occur in deeper ponds, generate smaller amounts of sludge than aerobic processes. Because these ponds are located outside, they are temperature sensitive and are therefore probably not applicable in Ontario. Figure C.8 shows a block flow diagram for waste stabilization.

Normal Operations

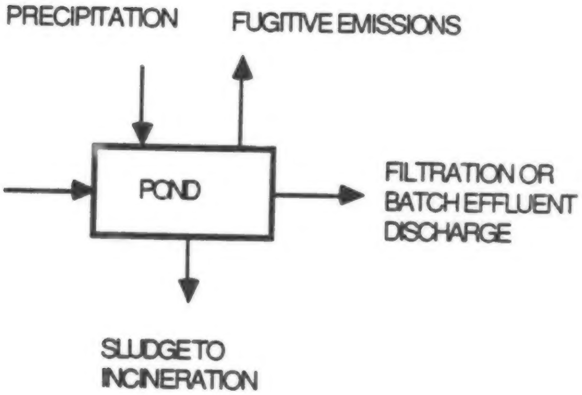
Under normal operating conditions, waste stabilization ponds result in the release of fugitive emissions to the atmosphere which may result in an odour problem. The sludge generated by the process can be dewatered and incinerated.

No special personal protective equipment is required.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions prior to emergency response if volatile wastes are inadvertently pumped into to the pond. Exposures of the off-site population to air releases are also possible but are unlikely to be dangerous due to dilution in the buffer zone around the ponds. The off-site environment is susceptible to contamination during floods in excess of the design capacity of the stabilization ponds. A failure in the pond liner may lead to a contamination of groundwater, possibly leading to human exposure through drinking water. Anaerobic operation may lead to odours such as from hydrogen sulfide.(1)

FIGURE C.8: WASTE STABILIZATION PONDS



Types of Waste Treatable (input flexibility)

Waste stabilization ponds can be used to treat some wastes in UCD category 225. These wastes should have a COD of less than 900 mg/L, phenols less than 10 mg/L, heavy metals less than 5 mg/L and a pH of from 7 to 8. Treatment is sensitive to pH, flow and toxic constituents.

Operational Flexibility (start up and shut-down as needed)

Waste stabilization ponds can be operated in either continuous or batch mode, that is the ponds may be filled and later drained or operated on a flow-through basis(1) if the retention time is long enough for adequate treatment to occur.

Unscheduled Downtime (operational reliability)

The simplicity of waste stabilization ponds results in low unscheduled downtime. Ponds that are not aerated do not involve mechanical equipment maintenance(1) and thus are simpler in operation than activated sludge systems.

Ease of Operation and Monitoring (technical reliability)

Waste stabilization ponds (non-aerated) are simpler to operate than any other biological treatment technology since they require no mechanical equipment other than pumps. Temperature must be closely monitored since treatment efficiency is highly temperature dependent and periodic monitoring for COD and suspended particulates is necessary. Sampling wells may be installed around a facility to detect groundwater contamination in sufficient time to allow corrective action to be taken.

Cost

Waste stabilization ponds with a capacity of 2,000 tonnes per year would have an operating cost of approximately $35 per tonne.

PHYSICAL SEPARATION PROCESSES

Physical separation processes remove contaminants from one medium or phase to another without actually destroying the contaminant. Thus, separation processes result in a concentrated liquid, solid, sludge, or slurry containing the removed hazardous material and a relatively clean effluent stream which is further treated, if necessary, or released directly.

Physical separation processes are used to treat aqueous organic wastes, oil/water emulsions, slurries and sludges containing less than 40% solids, and solutions containing heavy metals. Because the hazardous fraction of the waste stream is not destroyed, it must undergo further treatment or disposal.

AIR STRIPPING (1,2,4,19)

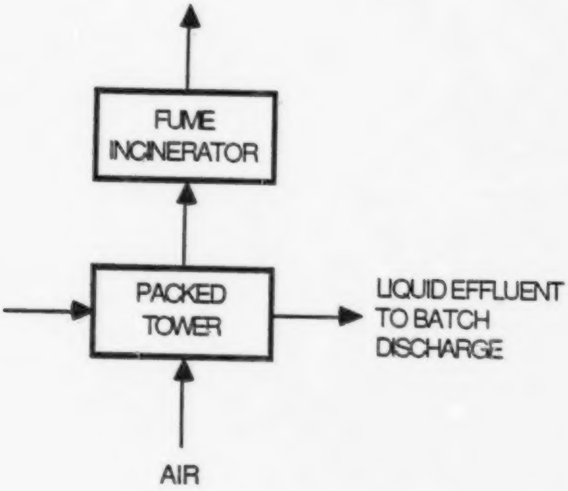
Process Description

Air stripping involves contacting air with a thin film of dilute aqueous solutions to remove volatile organics or ammonia in stripping towers. Air stripping has been used to clean waste waters and contaminated potable aquifers by removing volatiles, which are then released directly as air contaminants. In air stripping at an integrated special waste treatment facility, incineration or carbon adsorption of the contaminated air from stripping may be reset. An air stripping system is shown in Figure C.9.

Normal Operations

A properly operating air stripping unit should result in no uncontrolled releases to the environment. Contaminants removed from the wastewater to the air stream can be adsorbed, condensed or incinerated.

FIGURE C.9: AIR STRIPPING



No personal protective equipment is required for operators.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions in the event of leakage in the air stream prior to incineration, condensation, or adsorption. Personnel exposures are likely to be small, since wastes treated by air stripping are relatively dilute. Little waste is actually in the stripping tower at any time, thus minimizing the quantity of waste to which personnel might be exposed in the event of a catastrophic failure of the stripping tower. Prompt emergency response should minimize exposure to on-site personnel.

The buffer zone and dilution in the atmosphere should provide protection for surrounding populations in the event of a failure of the fume incinerator or other emission control system.

Types of Waste Treatable (input flexibility)

Although air stripping is not suitable for treatment of any UCD category as they are defined, some specific wastes are likely to be treatable by air stripping as will some secondary streams. Wastes in UCD categories 211-217, 221-228 have been assumed to be too high in organic content for air stripping and wastes in categories 281-285, 288, and 289 insufficiently volatile.

Operational Flexibility (start up and shut-down as needed)

Air stripping is normally carried out as a continuous operation. The process cannot be operated in a purely batch mode since the stripping process is inherently continuous (contaminants are transferred from a flowing aqueous stream to an air stream running countercurrent to it). The process may be operated, however, in a semicontinuous mode.

Unscheduled Downtime (operational reliability)

Air stripping has low (<5%) unscheduled downtime as the process is not easily upset by minor constituents in the waste stream. There are few moving parts, aside from a low-pressure pump and a fan; the process has been used for many years.(1)

Ease of Operation and Monitoring (technical reliability)

Air stripping is a relatively simple operation, requiring little operator support since steady state operation is usually achieved easily. Periodic monitoring of air emissions for volatile organics may be necessary to ensure proper operation of the incinerator or other pollution control equipment.

Cost

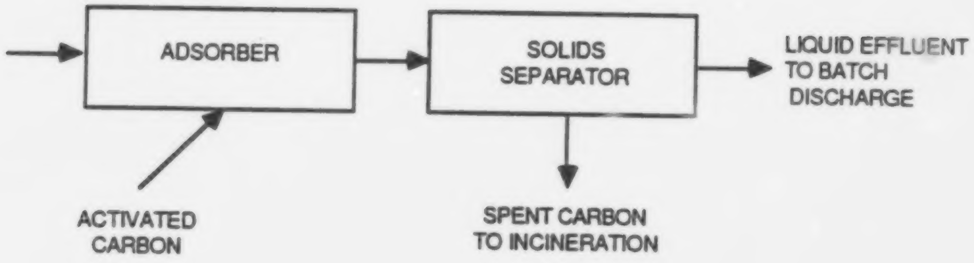
Operating cost for an air stripping unit of 2,000 tonnes per year are approximately $3 per tonne.

CARBON ADSORPTION (1,2,4,20-22)

Process Description

Carbon adsorption is frequently incorporated as a polishing step after treatment of aqueous organic waste to ensure that only trace quantities of organic constituents remain in the wastewater when it is released to the environment. Carbon adsorption effectively removes many but not all, organics and is generally limited to solutions with less than 5% total dissolved organics. The concentration limitation is due to the high cost of regenerating or replacing the spent carbon adsorbent; in most applications the organic carbon content is much less than 1%. A carbon adsorption system is illustrated in Figure C.10.

FIGURE C.10: CARBON ADSORPTION


ADSORBER
SOLIDS SEPARATOR
LIQUID EFFLUENT TO BATCH DISCHARGE
ACTIVATED CARBON
SPENT CARBON TO INCINERATION

Normal Operations

Carbon adsorption should result in no uncontrolled releases during normal operations. Contaminants removed from the wastewater are adsorbed onto the carbon, which can then be incinerated. Because contaminants either remain in the aqueous phase or are adsorbed onto the carbon, there is little possibility of exposure to personnel.

No special personal protective equipment is required.

Abnormal Events

On-site personnel may be exposed to contaminants during spills, as might occur in the event of a failure in the carbon adsorption vessel. Organics removed from the waste stream will remain adsorbed to the carbon, thus air releases are unlikely except for organics that may be volatilized from spilled liquid. There is little possibility of off-site contamination since any liquid released should be contained on-site. Thus, neither the off-site population nor the environment should be endangered by on-site spills.

Types of Waste Treatable (input flexibility)

Carbon adsorption can be used to treat some wastes from UCD categories 225 and 226. Wastes may require filtration prior to carbon adsorption. Suspended solids should not exceed 50 mg/L to prevent clogging of the carbon bed and organic components should normally be less than 10,000 mg/L.

Operational Flexibility (start up and shut-down as needed)

Carbon adsorption is a semi-continuous process, which must be shut down to replace spent carbon.

Unscheduled Downtime (operational reliability)

Pumps (low pressure) are the only mechanical devices used during treatment by carbon adsorption. Since there are few moving parts and because carbon adsorption systems have a history of successful operation(1) low (<5%) unscheduled downtime can be expected.

Ease of Operation and Monitoring (technical reliability)

Carbon adsorption units are not easily upset by minor constituents such as toxics that would upset a biological treatment process and have a low sensitivity to variations in feed rates and concentrations.(2) Thus, the systems are simple to operate. However, periodic monitoring for total organics, based on operator experience, and for the breakthrough of hazardous components in the effluent stream is necessary.

Cost

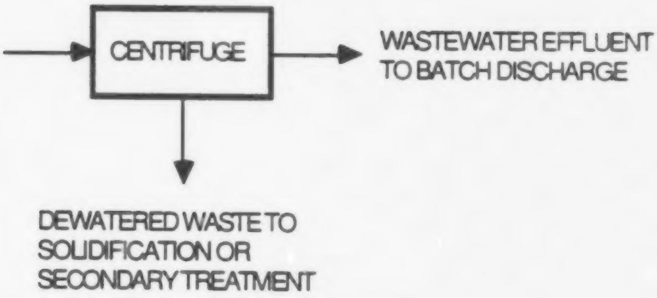
For a carbon adsorption unit with a capacity of 2,000 tonnes per year the estimated operating costs are $65 per tonne.

CENTRIFUGATION (1,2,4,23)

Process Description

Centrifugation is a process for separating suspended solids from liquids or for separating two immiscible liquid phases. In centrifugation, high centrifugal forces accelerate the separation. In most cases, when centrifuging liquids for removal of the solids, the maximum concentration of solids is limited to about 15%. Polyelectrolytes may be added to a augment to separation process for solid/liquid separations. Centrifugation is illustrated in Figure C.11.

FIGURE C.11: CENTRIFUGATION


CENTRIFUGE
WASTEWATER EFFLUENT TO BATCH DISCHARGE
DEWATERED WASTE TO SOLIDIFICATION OR SECONDARY TREATMENT

Normal Operations

There are no discharges to the external environment under normal operating conditions using centrifugation. The process results in a liquor that normally requires wastewater treatment only prior to release and a second stream, which is more concentrated in the hazardous material; this second stream can then be solidified and disposed of.

Personnel may be required to wear protective clothing and possibly respirators during maintenance, since they may come in contact with solid residuals.

Abnormal Events

On-site personnel may be exposed to flying debris or contaminants during catastrophic failure or spills. One such catastrophic failure is when the centrifuge physically breaks apart, due to imbalance. Leaks and spills will be small since there is little liquid in the centrifuge at any given time. Off-site personnel will not be exposed to contaminants, since any liquid will be retained on-site, and centrifugation results in no air releases. For the same reason, the surrounding environment will not be affected during on-site spills.

Types of Waste Treatable (input flexibility)

Centrifugation can be used to treat some wastes in UCD categories 141, 142, 145, 211, 212, 214, 215, 221, 251, 283, 288, 417, 431, 433, 441, 443, 445, 454 and 455. In general centrifugation will only be effective for sludges with less than 15% solids and for some oil/water emulsions.

Operational Flexibility (start up and shut-down as needed)

Centrifugation can be operated as a continuous or a batch process.

Unscheduled Downtime (operational reliability)

Centrifugation is not easily upset by minor constituents. The centrifuge baskets may become plugged during operation and the handling of abrasive solids can lead to maintenance problems caused by the rapid wearing of internal parts of the centrifuge.(2) Thus, moderate (5-20%) unscheduled downtime can be expected.

Ease of Operation and Monitoring (technical reliability)

Centrifugation is simple in operation, since it consists of only one piece of process equipment, unlike solvent extraction and steam stripping systems that require several. Periodic monitoring of percent solids in the liquid effluent is necessary to ensure that the solid material is being separated sufficiently by the process.

Cost

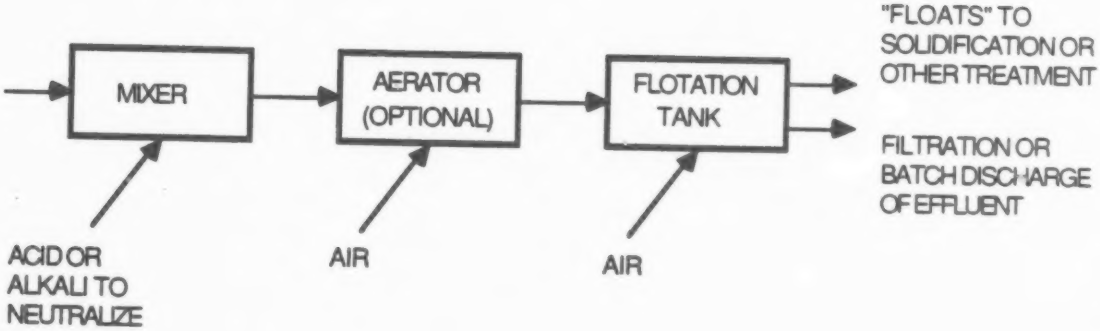
For a centrifugation unit with a capacity of 50,000 tonnes per year, the operating cost is estimated to be $2 per tonne.

DISSOLVED AIR FLOTATION (2,3,8,24-26)

Process Description

Dissolved air flotation is a process in which air is injected into aqueous wastewater solutions under pressure. The small air bubbles adhere to the surface of the particle causing the particles to become more bouyant and rise to the surface, where the floating matter is removed. Polyelectrolytes are sometimes added to increase removal efficiency.(8) The process has been used to separate organic sludges from the biological treatment wastewater, remove metal hydroxide particles after precipitation, and could be used for other wastes that have suspended particles. The process is illustrated in Figure C.12.

FIGURE C.12: DISSOLVED AIR FLOTATION


MIXER
AERATOR (OPTIONAL)
FLOTATION TANK
"FLOATS" TO SOLIDIFICATION OR OTHER TREATMENT
FILTRATION OR BATCH DISCHARGE OF EFFLUENT
ACID OR ALKALI TO NEUTRALIZE
AIR
AIR

Normal Operations

Dissolved air flotation results in no uncontrolled releases to the environment under normal operating conditions. The aqueous effluent is released or further treated as necessary. Sludge from the process can be incinerated or solidified and disposed of depending on its composition. Since the wastes being treated are non-volatile, no air releases should result from the process.

No special personal protective equipment is required of operators. Protective clothing and possibly respirators may be required during maintenance to prevent contact with any waste residues that adhere to the float collector.

Abnormal Events

On-site personnel may be exposed to waste in the event of a spill or failure in the flotation tank. Any liquid spills should be contained on site. Because non-volatile wastes are being treated, any air releases from a spill will be negligible.

Types of Wastes Treatable (input flexibility)

Some wastes from UCD categories 227, 228, 288 and 289 are amenable to dissolved air flotation. The waste must exist as a separate phase from the aqueous stream for successful treatment.

Operational Flexibility (start-up and shut-down as needed)

Dissolved air flotation systems can be operated as batch processes.(8)

Unscheduled Downtime (operational reliability)

Dissolved air flotation is the process employed most frequently in the thickening of sewage treatment sludges.(8) The equipment involved is relatively simple--sludge pumps, an air compressor, a flotation tank and skimmer, and chemical feed equipment if polymers are added to enhance separation. Thus, relatively low (<5%) unscheduled downtime can be expected.

Ease of Operation and Monitoring (technical reliability)

Dissolved air flotation is relatively simple in operation since essentially only one process unit is involved. Continuous operator attention is not required, but periodic checks are necessary.(8) The aqueous effluent from the system should be monitored periodically for suspended solids to ensure adequate separation is occurring.

Cost

For a system that treats approximately 10,000 tonnes per year, the operating costs are $35 per tonne.

ELECTRODIALYSIS (1,2,3,4,27)

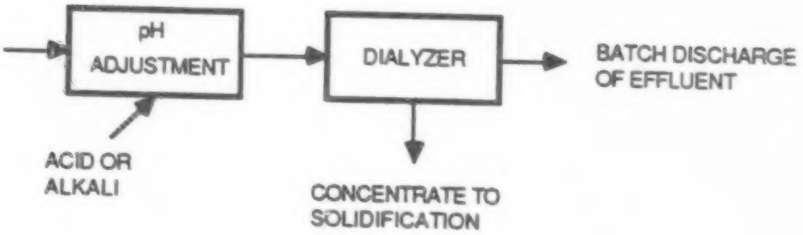
Process Description

Electrodialysis is a membrane process like reverse osmosis for separating dissolved salts from aqueous solutions. In this process electrical forces are used instead of pressure to force the permeate through the membrane. Electrodialysis has been used only in a few instances to treat hazardous waste. An electrodialysis block flow diagram is shown in Figure C.13.

Normal Operations

Electrodialysis results in no uncontrolled releases to the environment under normal operating conditions. Offgases from the dialyzer can be vented to an incinerator or through an activated carbon column; brine containing the more concentrated dissolved salts produced by the system can be solidified/stabilized.

FIGURE C.13: ELECTRODIALYSIS



No special personal protective equipment is required.

Abnormal Events

On-site exposure to personnel may occur during a spill as could occur due to a pipe or vessel failure, although the resident volume of waste in an electrodialyzer is small, reducing the risk (on-site) from spills. Any spill will be contained on-site and will not contaminate the surrounding environment or expose the neighboring population. On-site personnel may also be exposed to sulfuric acid (H_2SO_4), which is sometimes used for pre-treatment, in the event of a spill. Unwanted side reactions that occur during the process can lead to the formation of chlorine and hydrogen gas, which may lead to a health and explosive hazard in an enclosed space,(1) if they are not properly vented. However, it is unlikely that any gaseous emissions will contaminate off-site areas, since the amount of gas formation is small and any releases will be diluted through the buffer zone.

Types of Waste Treatable (input flexibility)

Electrodialysis is suitable for treatment of some wastes from UCD categories 141, 142, 145, and 251. Wastes must be filtered to remove suspended particles before they undergo electrodialysis and iron and manganese must be removed from the influent stream to prevent the degradation of most common membranes if their total concentration is greater than about 3 mg/L.(2) In general however, the process is not easily upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Electrodialysis is operated as a batch process.

Unscheduled Downtime (operational reliability)

Electrodialysis units used to treat influent streams of reasonably constant quality such as occur in desalination systems have a history of reliable operation and low unscheduled downtime. However, due to the irregularity of the wastes likely to be encountered in a waste treatment operation, electrodialysis can be expected to have a high (>20%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Electrodialysis is moderately complex in operation, since the influent must be carefully controlled. Continuous monitoring for dissolved salts and organics, with operator support, is necessary.

Costs

For an electrodialysis system with a capacity of 20,000 tonnes per year, the operating costs are estimated to be $2 per tonne.

EMULSION BREAKING (1)

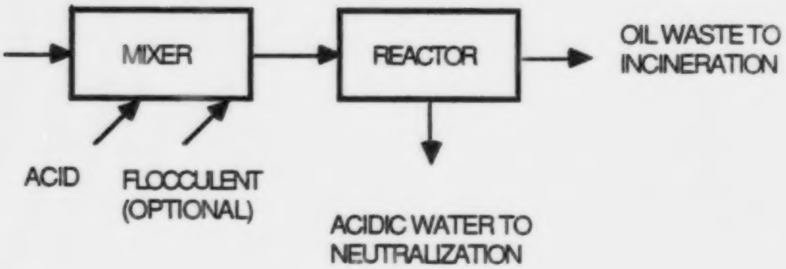
Process Description

Emulsion breaking separates oil from water emulsions. This can be the first step in oil recovery or in cleanup of the wastewater before it is released. Emulsion breaking can be accomplished several ways, including acidification, thermal swing, strong electric fields or centrifugation. For this study, it is accomplished by acidifying the aqueous solution to cause the two phases (oil and water) to separate because this is the technique most frequently used. Settling then takes place in a tank where the oil is skimmed from the surface of the water layer. An emulsion breaking system is illustrated in Figure C.14.

Normal Operations

As shown in Figure C.14, two streams result from emulsion breaking: an oily phase, which can be incinerated, and acidic water, which requires neutralization and other treatment, if required. Thus,

FIGURE C.14: EMULSION BREAKING



under normal operating conditions, there are no uncontrolled releases to the environment.

No special personal protective equipment is required.

Abnormal Events

On-site personnel may be exposed during spills. Since the capacity of the system envisaged for OWMC is not large, significant spills are unlikely. Spilled liquid will be contained on-site.

The possibility exists of small air releases from wastes containing volatile organics. On-site personnel could be exposed but dilution in the buffer zone and emergency response should protect the surrounding population and environment.

Types of Waste Treatable (input flexibility)

Emulsion breaking can be used to treat some waste from UCD categories 281, 282, 283, and 289.

Operational Flexibility (start up and shut-down as needed)

Emulsion breaking systems operate as batch processes.

Unscheduled Downtime (operational reliability)

Little equipment is required for emulsion breaking, merely a tank and pumps. Thus, emulsion breaking systems can be expected to have low (<5%) unscheduled downtime.

Ease of Operations and Monitoring (technical reliability)

Emulsion breaking is relatively simple in operation since it consists of only one process unit. Periodic monitoring (visual inspection) is required of the waste during the process to ensure that the emulsion has been separated. If the waste has a milky quality, further treatment is required to separate it into two phases, with a clear aqueous stream and oily solid resulting.

Cost

An emulsion breaking system with a capacity of 4,000 tonnes per year has an operating cost of approximately $20 per tonne.

EVAPORATION (1,2,3,4,28)

Process Description

Evaporation is used to concentrate liquids, slurries, and sludges that contain suspended or dissolved solids or liquids which are virtually non-volatile. Although solar evaporation ponds are used in some parts of the world, these would not be applicable in Ontario. Steam-heated, single-effect pan evaporators are used in this study. A brine concentrate, or wet solids, results from the process. An evaporation system is shown in Figure C.15.

Normal Operations

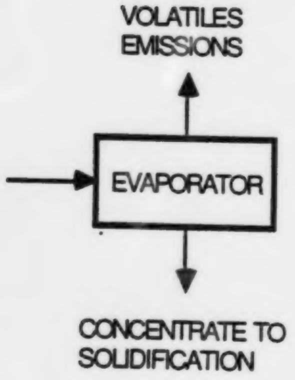
Under normal operating conditions, evaporation results in the air emissions of vapor containing moisture and trace quantities of inorganics. (Wastes containing volatile organics are not considered treatable by evaporation.) The brine or wet solids produced by the operation can be solidified/stabilized.

No special personal protective equipment is required for on-site personnel.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions from the evaporated vapor in the event of major failure of the

FIGURE C.15: EVAPORATION



evaporator or condenser. Off-site personnel and the surrounding environment should be protected from air releases, which would consist of steam and trace inorganics, by dilution in the buffer zone, as well as by emergency response by on-site personnel. On-site personnel may also be exposed during a spill of the waste. However, the spill should remain on-site and pose no problem to the surrounding community.

Types of Waste Treatable (input flexibility)

Evaporation is suitable for waste in UCD categories 141, 142, and 145. It is not generally used for cyanides (UCD 146), sulfides (UCD 147), or organic liquids (UCD 211-221) due to the high volatility of these wastes and the high reactivity or toxicity of sulfides and cyanides.

Operational Flexibility (start up and shut-down as needed)

Evaporation is operated as a batch process.

Unscheduled Downtime (operational reliability)

Evaporation is a proven technology where, in some cases, equipment has operated for decades with consistent results.(1) It is a relatively simple process requiring only pumps, a heat source, and the evaporators themselves. Thus, evaporation has low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (Technical Reliability)

Evaporation systems are easily operated with automatic monitoring of temperature.

Cost

For an evaporation system with a capacity of 75,000 tonnes per year, an operating cost of approximately $20 per tonne can be expected.

FILTRATION (1,2,4,9,29)

Process Description

Filtration is used to separate solids from liquids. Although many types of filters could be used in treatment of hazardous waste, including drum or belt filters, filter presses, pressure filters, sand or multi-media filters, the filter press has been used in this analysis. This allows the system to be charged with a particular waste, operated and then be cleaned before it is charged with the next waste. From input streams with 5 to 15% solids, a filter cake can normally be formed with 15 to 50% solids. The liquid effluent streams after filtration may contain residual suspended solids and dissolved solids that require additional treatment before release. A filtration system is shown in Figure C.16.

Normal Operations

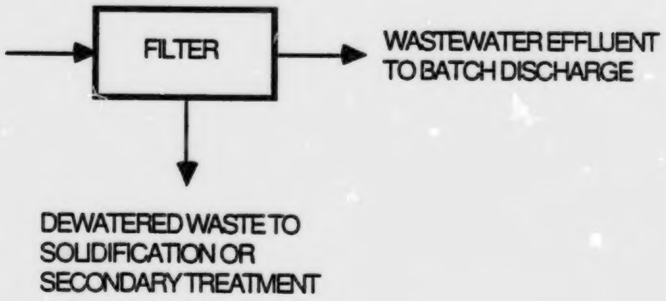
As shown in Figure C.16, filtration results in no uncontrolled releases to the environment during normal operations. Wastes that are removed from the treatment stream as a cake can be solidified. Aside from the contaminants in the treated wastewater, there are no other releases.

Protective clothing may be required for maintenance since workers are likely to come in contact with residual waste solids.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions from volatile organics prior to emergency response, in the event

FIGURE C.16: FILTRATION


FILTER
WASTEWATER EFFLUENT TO BATCH DISCHARGE
DEWATERED WASTE TO SOLIDIFICATION OR SECONDARY TREATMENT

of a failure of the air exhaust system. Dilution in the atmosphere and the buffer zone around the site will protect off-site personnel and the surrounding environment from exposure. Any liquid releases will be contained on-site.

Types of Wastes Treatable (input flexibility)

Some wastes from UCD categories 141, 142, 145, 251, 417, 431, 433, 441, 443, 445, 454, and 455 can be treated using filtration.

Operational Flexibility (start up and shut-down as needed)

Filtration is a batch process, when carried out on a filter press.

Unscheduled Downtime (operational reliability)

Filtration systems are not easily upset by minor constituents. Due to problems in solids handling such as clogging of the filters they have moderate (5%-20%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Although filtration consists of only one process unit, it is moderately complex in operation due to the problems associated with solids handling discussed before. Periodic monitoring for percent solids in the liquid effluent is required prior to discharge to ensure that adequate removal of solids from the liquid has occurred.

Costs

For a filtration system with a capacity of 50,000 tonnes per year a treatment of cost of approximately $2 per tonne results.

FLOCCULATION & SEDIMENTATION (1,2,4,8)

Process Description

Flocculation & sedimentation is used to remove suspended material from liquids. Chemical flocculants are added to the liquid to cause unsettleable particles or colloidal matter to agglomerate into larger, more settleable particles. After mixing with the flocculant, the liquid flows into a sedimentation basin where the floc settles from the liquid by gravity. A flocculation & sedimentation system is shown in Figure C.17.

Normal Operations

Under normal operating conditions, no uncontrolled releases to the environment should occur from flocculation & sedimentation systems. Slurry resulting from the process can be dewatered and solidified prior to disposal. There are no air releases, since only non-volatile wastes are treated.

Abnormal Events

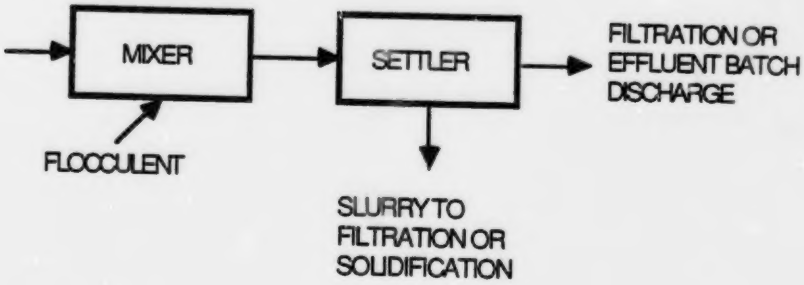
On-site personnel may be exposed to contaminants during a large spill. While flocculants such as alum, are strong skin irritants, they are easy to handle in a safe manner.(2) Off-site personnel and the surrounding environment will not be affected, since any spill will be contained on-site. Because there are no air releases from the process, off-site personnel will not be exposed through the atmosphere.

No special personal protective equipment is required for operators.

Types of Wastes Treatable (input flexibility)

Flocculation & sedimentation can be used to treat some wastes from UCD categories 141, 142, 145, 251, 262, 417, 431, 433, 441, 443,

FIGURE C.17: FLOCCULATION & SEDIMENTATION


MIXER
SETTLER
FILTRATION OR EFFLUENT BATCH DISCHARGE
FLOCCULENT
SLURRY TO FILTRATION OR SOLIDIFICATION

445, 447, 454, 455, and 523. Small quantities of certain materials, such as complexing organics and metal sulfides, will inhibit the flocculation/sedimentation process.(2)

Operational Flexibility (start up and shut-down as needed)

Flocculation/sedimentation is operated as a batch process.

Unscheduled Downtime (operational reliability)

Since the flocculant dosage is dependent on the waste being treated, unusual wastes may lead to process upsets, such as inhibition of flocculation or retardation of settling. Each batch of waste may require analysis to ensure consistency with previous batches, and if waste differs from previous batches, jar tests may be required to determine proper flocculant dosage. Consequently, flocculation & sedimentation has a moderate (5%-20%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Because of the need to control coagulant dosage, flocculation & sedimentation is moderately complex in operation. Periodic monitoring for suspended particulates in the effluent stream is required to ensure adequate removal and settling.

Cost

A flocculation & sedimentation system capable of treating 2,000 tonnes per year would result in a treatment cost of approximately $40 per tonne.

RESIN ADSORPTION (1,2,3,4)

Process Description

Resin adsorption is analogous to carbon adsorption, the difference being that synthetic polymeric adsorbents are used in the process rather than activated carbon. Like carbon adsorption, resin adsorption is used to remove organic solutes from an aqueous stream. Resins are normally tailored to remove one class of organics selectively from wastewaters containing other material. The presence of dissolved inorganic salts in the influent stream does not inhibit the adsorption of the organic solutes and in some cases may enhance it.(4) The adsorption resin is regenerated with non-aqueous solvents such as acetone or methanol (which may be distilled and reused) or with aqueous acid or caustic solutions.(4) Proven applications of resin adsorption are limited to the treatment of aqueous streams containing less than 8% dissolved organics.

Normal Operations

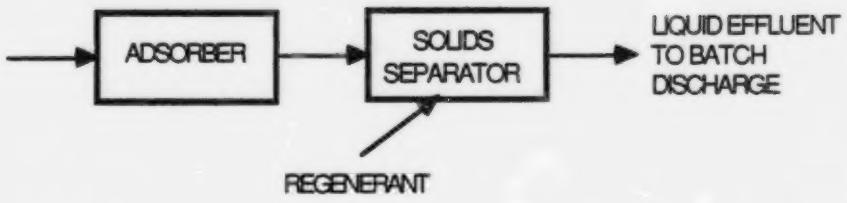
Resin adsorption, as shown in Figure C.18 causes no uncontrolled releases to the environment under normal operating conditions. The treated wastewater stream goes on to further treatment, if necessary, or is released. Contaminants adsorbed from the influent are removed from the resin in the regeneration step. The regeneration stream is smaller in volume and contains the organic contaminant at higher concentration than the original waste. The regeneration stream must be treated further (e.g., by incineration after distillation if a solvent regenerant is used). Rinse water, which is sometimes used before or after regeneration,(4) also goes on to further treatment as necessary.

No special personal protective equipment is required during normal operations. Protective clothing and/or respirators may be required during maintenance to avoid exposure to certain regenerants, such as acid, caustic or organic solvents (e.g., acetone or formaldehyde). Protective clothing would not be necessary for rinsing with water.

Abnormal Events

On-site personnel may be exposed to contaminants due to spills or leaks in the adsorption vessel. Worker exposure is likely to be small

FIGURE C.18: RESIN ADSORPTION



since wastes are relatively dilute, and little waste is actually in the adsorption vessel at any given time. Air releases caused by the volatilization of spilled waste are also likely to be small for the same reasons and because waste will tend to remain adsorbed to the resin in the event of a vessel failure. Workers could suffer potentially greater exposures if an equipment failure were to occur during regeneration with the organic solvent, caustic or acid. A solvent spill could cause air exposures as it volatilized, besides posing a fire hazard. Because any liquid spills would be contained on site, and the amount of solvent used in the regeneration step is small (several bed volumes),(4) the off-site population and environment will not be affected by on-site spills and would be protected from small volume air releases by dilution through the buffer zone.

Types of Waste Treatable (input flexibility)

Like carbon adsorption, resin adsorption can be used to treat some wastes from UCD categories 225 and 226. Suspended solids should be less than 50 mg/L (1) to prevent clogging of the bed. The feed stream should be kept at a consistent (though not necessarily neutral) pH since adsorption may be pH dependent.(4) Chemical constituents, such as strong oxidants that would attack the resins must be pretreated (by chemical reduction, for instance) before resin adsorption to protect them.(4)

Operational Flexibility (start-up and shut down as needed)

Resin adsorption can be operated as a batch process.

Unscheduled Downtime

Since the equipment and instrumentation configurations for resin adsorption systems are similar to those for carbon adsorption,(1) a similar low (<5%) unscheduled downtime can be expected.

Ease of Operation and Monitoring

Like carbon adsorption, resin adsorption is not easily upset by minor constituents. Periodic monitoring of the effluent stream for key components (based on operator experience) is necessary to determine when regeneration is required.

Cost

Resin adsorption costs of $85 tonnes of waste are typical for a small system that treats 5,000 tonnes per year. This system includes regeneration of resin.

REVERSE OSMOSIS (1,2,3,4,27)

Process Description

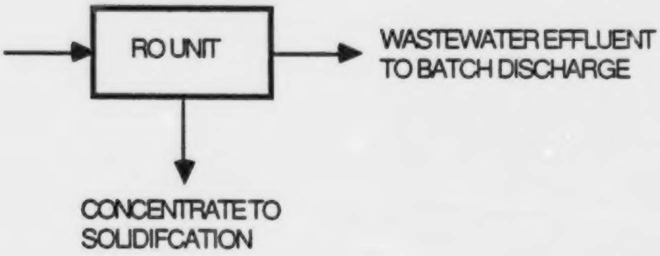
Reverse osmosis is a separation process for removing dissolved salts from water by forcing liquids through semi-permeable membranes, by pressure. This process has been used most notably for the desalination of sea water but has also been used in polishing wastewater from treatment prior to release. A reverse osmosis system is shown in Figure C.19.

Normal Operations

As shown in Figure C.19, there are no uncontrolled releases from reverse osmosis systems under normal operating conditions. Brine resulting from the system can be solidified prior to disposal. There are no emissions to the atmosphere from the process.

No special personal protective equipment is required.

FIGURE C.19: REVERSE OSMOSIS


RO UNIT
WASTEWATER EFFLUENT TO BATCH DISCHARGE
CONCENTRATE TO SOLIDIFCATION

Abnormal Events

On-site personnel may be exposed in the event of a spill caused by a pump or vessel failure. Any spills will be contained on-site and not contaminate the surrounding environment or expose the neighboring population. No releases to the atmosphere will occur, since no gases are produced by reverse osmosis.

Types of Wastes Treatable (input flexibility)

Some waste from UCD categories 141, 142, and 145 may be treated by reverse osmosis. Minor constituents easily upset reverse osmosis systems and the waste stream must be filtered to remove suspended solids prior to treatment to prevent plugging.(1) Film-forming organics in the feed stream may foul the membrane and should also be removed along with oxidizers such as iron and manganese salts.

Operational Flexibility (start up and shut-down as needed)

Reverse osmosis can be operated as a batch process.

Unscheduled Downtime (operational reliability)

Reverse osmosis systems have high (>20%) unscheduled downtime. In part this is because chemical contaminants in the waste stream may react with the system's membranes. Also, since the system operates at high pressure, there is a potential for pump and seal problems.

Ease of Operation and Monitoring (technical reliability)

Reverse osmosis is moderately complex in operation due to the need to eliminate problem substances from the influent stream. Continuous monitoring for dissolved solids and operator support is required.

Cost

A reverse osmosis system with a capacity of 2,000 tonnes per year has an operating cost of approximately $1 per tonne.

SOLVENT EXTRACTION (1,2,3,4,30,31)

Process Description

Solvent extraction is used to separate selected constituents from aqueous solutions. It has been used primarily for recovery of organics such as phenol and acetic acid but has also been used for separation of some metals and cyanide. The identified constituents are removed from the waste stream by selective adsorption into a second liquid. The wastewater is then further treated, if required, or released. The separated constituents must then be treated by other appropriate treatment steps. The process is illustrated in Figure C.20.

Normal Operations

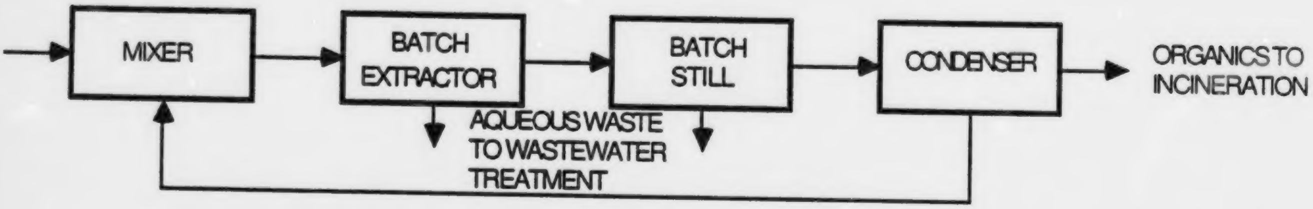
Solvent extraction results in no uncontrolled releases to the environment under normal operating conditions. As Figure C.20 shows, both the wastewater and the organic waste from the system go on to further treatment.

During maintenance, personnel may be required to wear a respirator to protect them from exposure to wastes remaining in the system and the solvent used in the extraction process.

Abnormal Events

The flammability of the solvent used as the extraction reagent results in the possibility of fire or explosion on-site. Exposure of on-site personnel is possible prior to emergency response. The surrounding population may be exposed to air releases in the event of

FIGURE C.20: SOLVENT EXTRACTION



a fire. These releases would consist of burning and volatilized solvent. Spill of liquids would be contained on-site.

Types of Wastes Treatable (input flexibility)

Some wastes from UCD categories 227, 228, and 288 are amenable to treatment by solvent extraction. The process is not easily upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Solvent extraction can be operated as a batch process.

Unscheduled Downtime (operational reliability)

Phenol recovery by solvent extraction has been practiced by steel mills and refineries for decades.(1) Thus, the technology is well developed, and solvent extraction systems can be expected to have low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Solvent extraction systems consist of several process units and thus are moderately complex in operation. Continuous monitoring for dissolved organics in the aqueous effluent stream is necessary to ensure adequate extraction of the contaminants and sufficient separation of the solvent from the water. Operator support is required to operate the process in batch mode.

Cost

A solvent extraction system with a capacity of 100 tonnes per year results in a treatment cost of approximately $75 per tonne.

STEAM STRIPPING (1,2,3,4)

Process Description

Steam stripping, like air stripping, is used to remove low levels of volatile organics from aqueous solutions. Steam stripping is suitable for a wider range of organics than air stripping and does not create a contaminated air stream that requires subsequent treatment. Instead, steam stripping creates a stream of condensed steam and organics. The smaller stream then requires treatment by incineration or other appropriate techniques.

Normal Operations

A properly operating steam stripping unit should result in no uncontrolled releases to the environment, as shown in Figure C.21. Contaminants removed from the wastewater to the air stream can be destroyed by incineration.

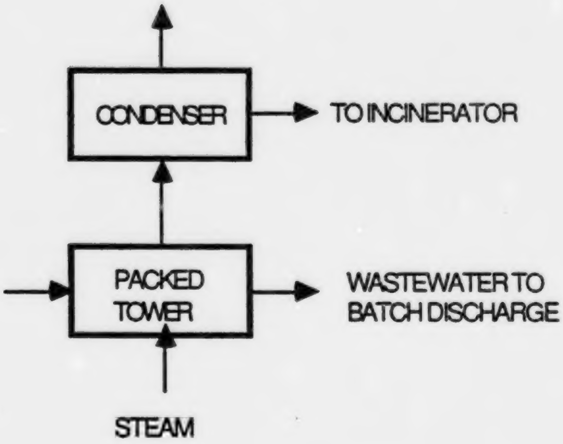
No personal protective equipment is required for operators.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions in the event of leakage in the fume stream prior to incineration. Spills of incoming wastewater may also result in exposure of on-site personnel as the aqueous wastes are volatilized in the air. Prompt emergency response should minimize exposure to on-site personnel. Furthermore, waste streams are of low concentration, thus minimizing the quantity of organics likely to be volatilized.

The buffer zone around steam stripping units and dilution in the atmosphere should provide protection for surrounding populations in the event of a failure of the condenser or fume incinerator.

FIGURE C.21: STEAM STRIPPING



Types of Wastes Treatable (input flexibility)

Although steam stripping is not suitable for treatment of any UCD category as they are defined, some specific wastes are likely to be treatable by steam stripping, as will some secondary streams. Steam stripping can treat a greater variety of waste than air stripping. Wastes in other UCD categories (211-217, 221-228) have been assumed to be too high in organic content or insufficiently volatile for stripping (UCD categories 281-285, 288, 289).

Operational Flexibility (start up and shut-down as needed)

Steam stripping can be operated as a batch process.

Unscheduled Downtime (operational reliability)

Since there are few moving parts (except for pumps) in steam stripping systems and because steam stripping has a history of successful operation,(1) there is low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Steam stripping is complex in operation. Periodic monitoring for volatile organics is necessary to ensure proper operation of the fume incinerator in the effluent streams and adequate removal from the aqueous stream.

Cost

For a steam stripping system with a capacity of 2,000 tonnes per year, the estimated operating cost is $10 per tonne.

ULTRAFILTRATION (1,2,3,4,27)

Process Description

Ultrafiltration is a membrane separation process like reverse osmosis but is less able to separate small molecules of dissolved salt than is reverse osmosis. Both use pressure to force the water through a membrane that allows water to pass through while the contaminant is retained on the "high pressure" side.

Normal Operation

As shown in Figure C.22, there are no uncontrolled releases from ultrafiltration systems under normal operating conditions. The concentrated stream resulting from the system can be solidified prior to disposal. There are no emissions to the atmosphere from the process.

No special personal protective equipment is required.

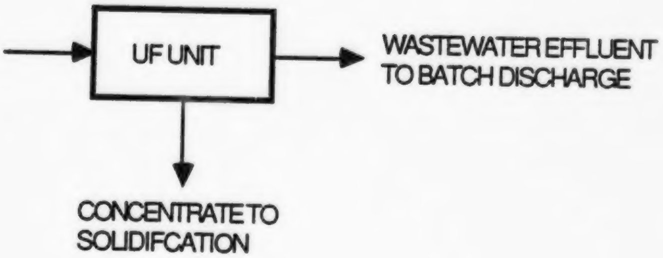
Abnormal Events

On-site personnel may be exposed in the event of a spill which may occur due to a failure in the vessel or seals. Small volume air releases are also possible if volatile wastes are being treated. In no case will the surrounding population or environment be affected, however. Spills will be contained on-site and the buffer zone surrounding the site will provide adequate dilution for air releases.

Types of Wastes Treatable (input flexibility)

Although ultrafiltration is not suitable for treatment of any UCD as they are defined, some specific wastes are likely to be treatable by ultrafiltration as will some secondary streams. The system is easily upset by minor constituents in the waste. In addition, strong oxidizing agents, solvents, and other organics that can degrade the

FIGURE C.22: ULTRAFILTRATION


UF UNIT
WASTEWATER EFFLUENT TO BATCH DISCHARGE
CONCENTRATE TO SOLIDIFCATION

membrane should be removed or chemically transformed in a pretreatment train.(1)

Operational Flexibility (start up and shut-down as needed)

Ultrafiltration, like reverse osmosis, can be operated as a batch process.

Unscheduled Downtime (operational reliability)

Ultrafiltration can be expected to have high (>20%) unscheduled downtime due, in part, to its sensitivity to contaminants in the incoming waste stream. Scaling can also be a problem(1) and the elevated pressure (70-700 kPa) at which the system operates is more likely to lead to seal or vessel failure than technologies operating at or near atmospheric pressure.

Ease of Operation and Monitoring (technical reliability)

Ultrafiltration is moderately complex in operation since the temperature, pH, chlorine concentration, and pressure of the feed stream all affect the performance of ultrafiltration units,(1) and thus require careful control. Continuous monitoring for dissolved solids and organics is necessary, and operator support is required.

Cost

For an ultrafiltration system with a capacity of 20,000 tonnes per year, the estimated operating cost is approximately $2 per tonne.

CHEMICAL TREATMENT PROCESSES

Chemical treatment processes are used to convert the hazardous components of a waste stream to less hazardous forms by chemically reacting the hazardous substances. Several types of reactions are employed to effect the desired changes. Acid-base reactions, for example, are used to neutralize acidic or basic solutions converting them to neutral salt solutions. In many cases, metal hydroxide precipitates form, enabling subsequent removal of hazardous constituents. Oxidation-reduction reactions are used, for example, to oxidize cyanides and reduce chromium to less toxic forms. Each chemical treatment process can treat only a narrow range of wastes based on the chemical reaction required.

Various organic and inorganic wastes are treatable chemically. The types of chemical treatment technology used, however, may be highly specific to the actual waste being treated.

Chemical treatment processes result in a treated waste stream from which the hazardous constituents have been removed (e.g., by ion exchange or precipitation) or rendered less hazardous (all other processes considered). The regeneration of ion exchange media produces a concentrated aqueous waste stream, and spent media must be landfilled. Precipitation creates a sludge to be treated and disposed of.

CHEMICAL OXIDATION (1,2,3,4)

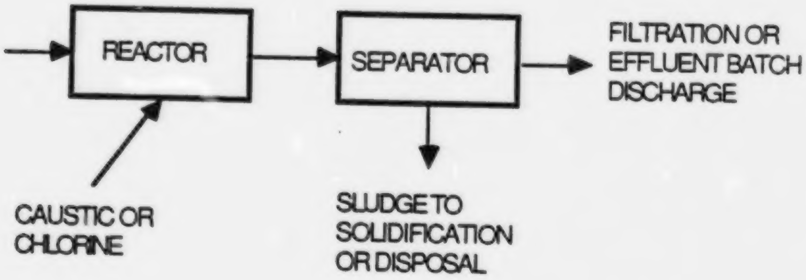
Process Description

Chemical oxidation is a process wherein oxidizing reagents such as chlorine, chlorine dioxide, ozone, or hydrogen peroxide(1) are used to oxidize cyanide and sulfide in alkaline solutions. This process can be carried out in an enclosed tank, which is monitored to determine the extent of the reaction. From the oxidation tank the solution can then be further treated as needed by physical or chemical treatment processes.

Normal Operations

No uncontrolled releases to the environment occur with chemical oxidation under normal operating conditions as shown in Figure C.23.

FIGURE C.23: CHEMICAL OXIDATION



The pH must be carefully controlled to ensure no releases occur of hydrogen cyanide or hydrogen sulfide, both of which are highly toxic gases. The effluent stream goes on to further treatment and any sludge produced can be solidified prior to disposal.

Protective clothing and respirators may be required for reagent handling to prevent contact with or inhalation of the oxidizing agent.

Abnormal Events

When chlorine gas is used as the oxidizing agent the possibility exists of uncontrolled gaseous emissions. Besides exposing on-site personnel, the surrounding population may be exposed to large or highly dangerous air releases of chlorine gas. The possibility of a large gaseous release from systems that employ ozone is less likely since ozone must be generated on site, hence, smaller quantities of the oxidant would be present at the facility. Spills of the waste to be treated may expose on-site personnel but will be contained on-site.

Types of Waste Treatable (input flexibility)

Chemical oxidation can be used to treat wastes in UCD categories 143 (oxidizable wastes only), 146, 147, and 444. The process is not easily upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Chemical oxidation systems can be operated as batch processes.

Unscheduled Downtime (operational reliability)

Chemical oxidation systems like chemical reduction systems have relatively simple equipment requirements (pumps, metering instrumentation etc.) when alkaline chlorination is employed.(1) Thus, chemical oxidation systems can be expected to have low (<5%) unscheduled downtime. Use of ozone as the oxidant greatly increases the equipment complexity because of the need for ozone generation equipment.(1) For the purposes of this report, chlorine is assumed to be the oxidant employed.

Ease of Operation and Monitoring (technical reliability)

Chemical oxidation systems are relatively complex in operation due to the number of steps involved. As Figure C.24 shows, the pH must be raised (to prevent the formation of HCN gas), the oxidant added and solids separated. Periodic monitoring for reactive anions in the effluent must be performed to ensure that the waste has been completely oxidized.

Cost

For a chemical oxidation system with a capacity of 3 100 tonnes per year, the estimated treatment cost is $35 per tonne.

CHEMICAL REDUCTION (1,2,3,4)

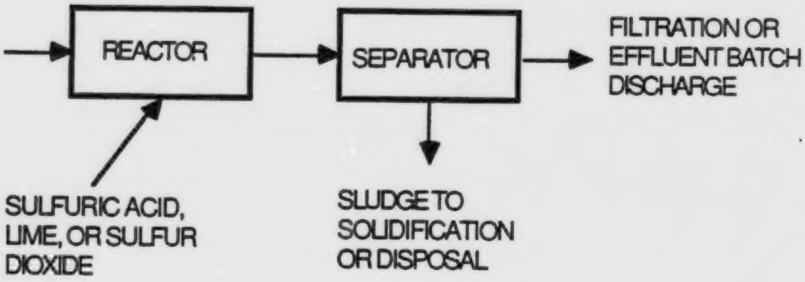
Process Description

Chemical reduction is the selective process for reducing the hazard of certain species. Reduction of hexavalent chromium to the trivalent forms that are significantly less harmful in the environment, using reducing agents such as sulfur dioxide, sodium metabisulfite or ferrous sulfate is one example.(1) Other metals such as silver and mercury can also be reduced in a similar manner.

Normal Operations

Chemical reduction results in no uncontrolled releases to the atmosphere, as shown in Figure C.24. Sludge that results from the process can be solidified prior to disposal. The effluent stream goes on to further wastewater treatment.

FIGURE C.24: CHEMICAL REDUCTION


REACTOR
SEPARATOR
FILTRATION OR EFFLUENT BATCH DISCHARGE
SULFURIC ACID, LIME, OR SULFUR DIOXIDE
SLUDGE TO SOLIDIFICATION OR DISPOSAL

Protective clothing and respirators may be required for waste handling to prevent contact with the chromium wastes and unreacted reducing agents.

Abnormal Events

Sulfur dioxide gas is often used as the reducing agent due to its low cost and ease of handling.(2) Where it is used, the possibility exists of uncontrolled gaseous emission. While on-site personnel may be exposed, populations surrounding the site should be protected by buffer zone and dilution in atmosphere. Liquid spills may expose operating personnel but will be contained on-site and not affect the surrounding population or environment.

Types of Waste Treatable (input flexibility)

Chemical reduction can be used to treat wastes in UCD categories 143 (reducable wastes only) and 251. The process is not easily upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Chemical reduction systems can be operated as batch processes.

Unscheduled Downtime (operational reliability)

Chemical reduction systems have relatively simple equipment requirements--storage, metering, mixing, pumping, and instrumentation.(1) Besides simple equipment, the process is operated in batch thus low (<5%) unscheduled downtime can be expected.

Ease of Operation and Monitoring (technical reliability)

Chemical reduction is considered complex in operation because of the number of steps involved (see Fig. C.23: acidifying the waste, adding and mixing the reductant, increasing the pH, removing the solids) and the need to control the quantity of each reagent added. Periodic monitoring for Cr (VI) level is necessary to ensure that sufficient quantity of reducing agent is used in the process.

Cost

For a chemical reduction system with a capacity of 2,000 tonnes per year, operating costs are roughly $35 per tonne.

DEHALOGENATION (1,32,33)

Process Description

Dehalogenation is used to remove chlorine atoms from chlorinated organics, thereby rendering them less hazardous. A highly reactive reagent such as sodium or sodium naphthalide is employed to accomplish the chlorine stripping as shown in Figure C.25. The process is a proven technology only for PCB-containing oils.

Normal Operation

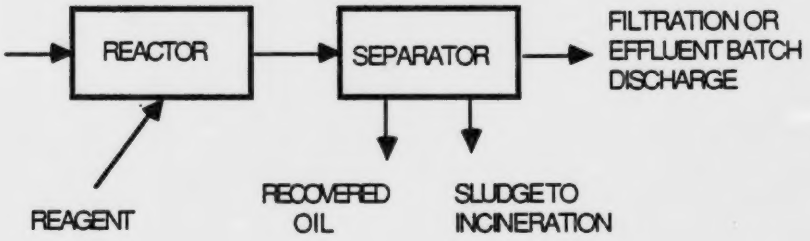
Under normal operating conditions, dehalogenation results in no uncontrolled emissions to the environment. Oil is recovered from the process, which can then be incinerated or recycled. Sludge containing water, NaCl, biphenyls, polyphenyls, and low concentrations of PCB can be incinerated provided the sodium concentration is not too high. A wastewater stream results which is further treated.

Protective clothing may be required for sludge handling to protect against contact with PCB's or reagent.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions in the event that water comes in contact with the sodium reagent thereby producing highly explosive hydrogen gas and sodium hydroxide.

FIGURE C.25: DEHALOGENATION



These air releases may expose the surrounding population if large enough, and may reach explosive concentrations on site. However, they are unlikely to reach explosive concentrations off site due to dilution in the buffer zone. Operating personnel may also be exposed to the extremely reactive reagents used in the process. Liquid spills will be contained on site.

Types of Wastes Treatable (input flexibility)

Dehalogenation can be used to treat wastes in UCD category 242. Oils must be virtually free of water for safe and economical use of sodium as the reagent as the sodium will react preferentially with the water.

Operational Flexibility (start up and shut-down as needed)

Dehalogenation is operated as a batch process.

Unscheduled Downtime (operational reliability)

Dehalogenation is not easily upset by minor constituents other than water, and no complicated equipment is required. For these reasons and because it is a batch process dehalogenation can be expected to have low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Dehalogenation is complex in operation because of the number of steps involved in the process; viz, adding the highly reactive reagent, removing solids from the separator, etc. Periodic monitoring for PCB is required to ensure adequate dehalogenation has occurred.

Cost

For a dehalogenation system capable of treating 40 tonnes per year, a treatment cost of approximately $1,000 per tonne results.

ION EXCHANGE (1,2,3,4,34,35,36,37,38)

Process Description

Ion exchange is used primarily to remove inorganic ions from an aqueous or partially aqueous phase. The process involves passing the waste over the solid ion exchange material. Ions in the aqueous phase are exchanged for other ions on the ion exchange material surface. Eventually the exchange sites on the ion exchange material are used up and the material is regenerated using a concentrated aqueous solution of exchanger ions which removes the contaminant ions from the ion exchange material. The ion exchanger is then available for use in treating more waste.

Normal Operation

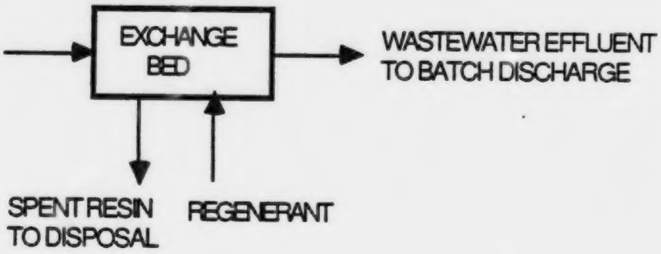
As shown in Figure C.26, ion exchange serves to transfer the contaminant ions from the wastewater stream to a concentrated spent regenerant stream. Under normal operating conditions, there are no uncontrolled releases to the environment using ion exchange.

No special personal protective equipment is required.

Abnormal Events

Ion exchange materials are not hazardous. Thus the exposure of on-site personnel is limited to the waste stream and the regenerant. Operating personnel may be exposed to contaminants during a spill. Because there are no air releases from the process, and because any spill will be contained on-site, the surrounding environment and population will not be exposed.

FIGURE C.26: ION EXCHANGE



Types of Waste Treatable (input flexibility)

Ion exchange can be employed to treat some wastes from UCD categories 111, 112, 121, 122, 141, and 142. Ion exchange is not easily upset by minor constituents but wastes must be low in suspended solids to prevent fouling and in oxidizing material to prevent degrading of the exchange resin.

Operational Flexibility (start up and shut-down as needed)

Ion exchange systems can be operated as batch processes.

Unscheduled Downtime (operational reliability)

Aside from pumps and vessels, little equipment is required for ion exchange. The technology is well proven and has a history of successful operation in industrial applications.(1) Thus, ion exchange systems have low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Ion exchange systems are considered moderately complex in operation because a regeneration step is involved. Continuous monitoring for dissolved salts is necessary to determine when the ion exchange material is exhausted. Operator support is required to to operate the regeneration system.

Cost

An ion exchange system with a capacity of 20,000 tonnes per year has an operating cost of approximately $5 per tonne.

NEUTRALIZATION (1,2,3,4)

Process Description

Neutralization is the process of adding acids or based to aqueous solutions to create neutral aqueous salt solutions. This is normally the first step in treating aqueous waste that is outside of the pH range of approximately 6-8. This process takes place in stirred tanks, frequently with automatic controls for monitoring the addition of neutralizing agents to ensure efficient and safe operation. Waste acids and bases can be used as the neutralizing agent. The neutralization process is shown in Figure C.27.

Normal Operation

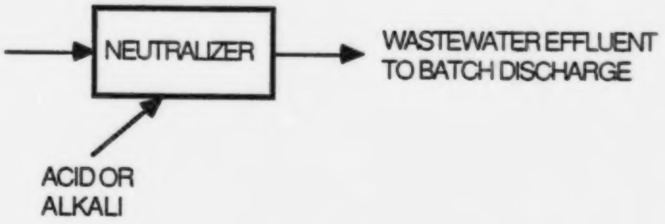
Neutralization usually results in only one effluent stream, i.e., the wastewater that has been treated. However, the neutralization of an acidic waste containing heavy metals (zinc, lead, cadmium, chromium, copper, and mercury) will generally cause some fraction of the metals to precipitate; if a precipitate forms it is assumed that the process is "precipitation" not "neutralization". There are no uncontrolled releases to the environment during normal operations.

No special personal protective equipment is required for operating personnel.

Abnormal Events

Spills may result in the exposure of operating personnel to caustic or acid used in neutralizing the wastewater, or to the wastewater itself. Any spills will be contained on-site. There are no air releases from neutralization (provided only appropriate wastes are treated); hence the surrounding environment and population will not be exposed. Adding acid to neutralize waste streams containing cyanides or sulfides may result in the release of toxic hydrogen cyanide or hydrogen sulfide gases respectively, thus exposing on-site personnel.

FIGURE C.27: NEUTRALIZATION



The addition of reagents must be closely controlled to prevent excessive heat releases.

Types of Waste Treatable (input flexibility)

Neutralization can be used to treat wastes in UCD categories 113, and 123. Wastes containing sulfides and cyanides should not be neutralized unless the system is equipped to treat gaseous emissions (see "Abnormal Events"). The process is not easily upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Neutralization can be operated as a batch process.

Unscheduled Downtime (operational reliability)

Neutralization requires no complicated equipment and is in full scale use throughout many industries.(1) Hence, low (< 5%) unscheduled downtime can be expected.

Ease of Operation and Monitoring (technical reliability)

Neutralization is relatively simple since essentially only one step is involved (provided precipitation is not involved). Monitoring of the effluent pH and control of the addition of caustics or acids for neutralization is usually done automatically, this minimizing the need for operator support.

Cost

Neutralization systems capable of treating 21,000 tonnes per year would have an operating cost of approximately $10 per tonne.

PRECIPITATION (1,2,3,4)

Process Description

Precipitation involves forming solid precipitates from inorganic waste in solution, normally by changing the degree of acidity (pH) or adding small quantities of other reactants. This technique is particularly effective in reducing concentrations of heavy metals in solution, essential before the release of those solutions to the environment. The solid precipitate which contains the metals can then be removed by settling and filtration as shown in Figure C.28.

Normal Operation

Under normal operating conditions no uncontrolled releases to the environment occur with precipitation. Waste removed from the stream forms a sludge, which can be solidified prior to landfilling. The treated stream goes on to further wastewater treatment. There are no other effluents from the process.

No special personal protective equipment is required for operating personnel.

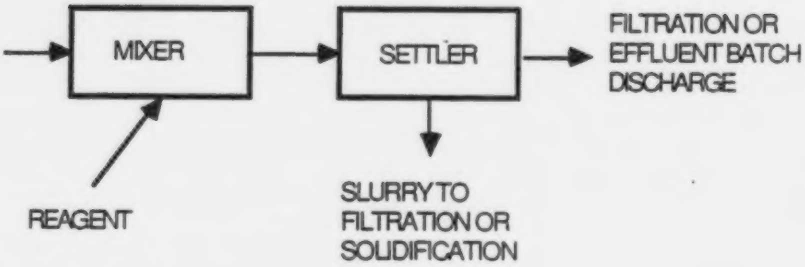
Abnormal Events

Spills may result in the exposure of on-site personnel to the aqueous waste or the reagents used in the precipitation process. Any spills will be contained on-site. Since the wastes amenable to precipitation typically contain no volatile components, and since the precipitation process results in no air emissions, the surrounding population and environment will not be exposed.

Types of Waste Treatable (input flexibility)

Waste in UCD categories 111, 121, 122, 131, 132, 133, 141, and 142 are treatable by precipitation. Precipitation is not easily upset

FIGURE C.28: PRECIPITATION


MIXER
SETTLER
FILTRATION OR EFFLUENT BATCH DISCHARGE
REAGENT
SLURRY TO FILTRATION OR SOLIDIFICATION

by minor constituents, although it is sometimes not effective if metals are tied up in very stable complexes in solution, as occurs in many electroplating wastes.(2)

Operational Flexibility (start up and shut-down as needed)

Precipitation systems can be operated as batch processes.

Unscheduled Downtime (operational reliability)

The equipment employed for precipitation is relatively simple and is well established in many industries.(1) Like all the other chemical treatment technologies considered here (except wet air oxidation) precipitation systems have low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Since no complicated equipment is required and only two process steps are used, precipitation is simple in operation. Periodic monitoring for dissolved solids is required to ensure adequate precipitation is occurring, and suspended solids are monitored to ensure sufficient solids separation takes place.

Cost

A precipitation system capable of treating 20,000 tonnes per year would have an operating cost of approximately $110 per tonne.

WET AIR OXIDATION (1,39,40,41,42,43)

Process Description

Wet air oxidation is a chemical oxidation technology that operates at lower temperatures and higher pressures than the thermal destruction technologies considered. It is particularly well-suited for treatment of aqueous solutions of 1%-5% dissolved organics and can handle both liquids and sludges with limited chlorine content. Unlike thermal destruction, wet air oxidation does not degrade organics to carbon dioxide and water completely, but produces an aqueous stream that must be further treated biologically.

Normal Operation

As shown in Figure C.29 there are no uncontrolled releases from wet air oxidation systems under normal operating conditions. The liquid effluent from the treatment process goes on to further biological treatment. Offgas from the separator is incinerated and sludge from the separator can also be incinerated.

Abnormal Events

Because wet air oxidation systems operate at elevated temperatures and pressure, the possibilities of fire and explosion exist. On-site personnel may be exposed, and the off-site population may be affected by large or highly dangerous air releases. Any liquid spills will be contained on-site.

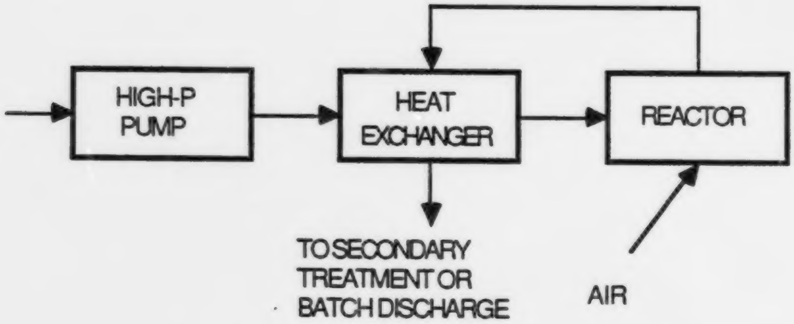
Types of Wastes Treatable (input flexibility)

Wet air oxidation can be used to treat waste in UCD categories 225-227, 252, 254, 283, 289, 447, and 523. Wastes should have a COD high enough to ensure that the process is thermally self-sustaining.(40) Wet air oxidation has not been particularly successful in treating highly halogenated wastes.(40)

Operational Flexibility (start up and shut-down as needed)

Wet air oxidation systems are operated continuously whether air or oxygen is used in the system.(1)

FIGURE C.29: WET AIR OXIDATION



Unscheduled Downtime (operational reliability)

The elevated temperatures and pressures at which wet air oxidation systems operate increase the potential for operating problems. In some installations, annual maintenance costs have amounted to almost 10% of the initial capital cost.(1) For these reasons and because most applications of wet air oxidation systems have been for the treatment of sewage sludge rather than hazardous waste, high (>20%) unscheduled downtime can be expected.

Ease of Operation and Monitoring (technical reliability)

Because of the number of pieces of process equipment involved, and the conditions under which they operate, wet air oxidation is considered complex in operation. Monitoring of temperature and pressure in the system is done automatically.

Cost

A wet air oxidation system capable of handling 25,000 tonnes per year would have an operating cost of approximately $15 per tonne.

THERMAL TREATMENT PROCESSES

Thermal processes are used to destroy organic wastes by oxidizing them at high temperatures up to 1400°C. The wastes are combusted directly, as in the various forms of incineration, or in the case of pyrolysis the organics are broken down thermally in an oxygen-starved environment and the resulting volatile organics combusted.

All organic wastes are considered to be treatable by thermal destruction. These wastes can be in the form of sludges, slurries, solutions or solids, and can consist of mixtures of organics with inorganics or water, or be entirely organic.

All of the thermal treatment processes considered result in flue gases that must be treated and (with the exception of liquid injection incineration) unburned solid residue to be disposed of. A solid salt or liquid effluent also results as a discharge from the air pollution control equipment.

FLUIDIZED BED INCINERATION (1,3,4,44,45,46,47,48)

Process Description

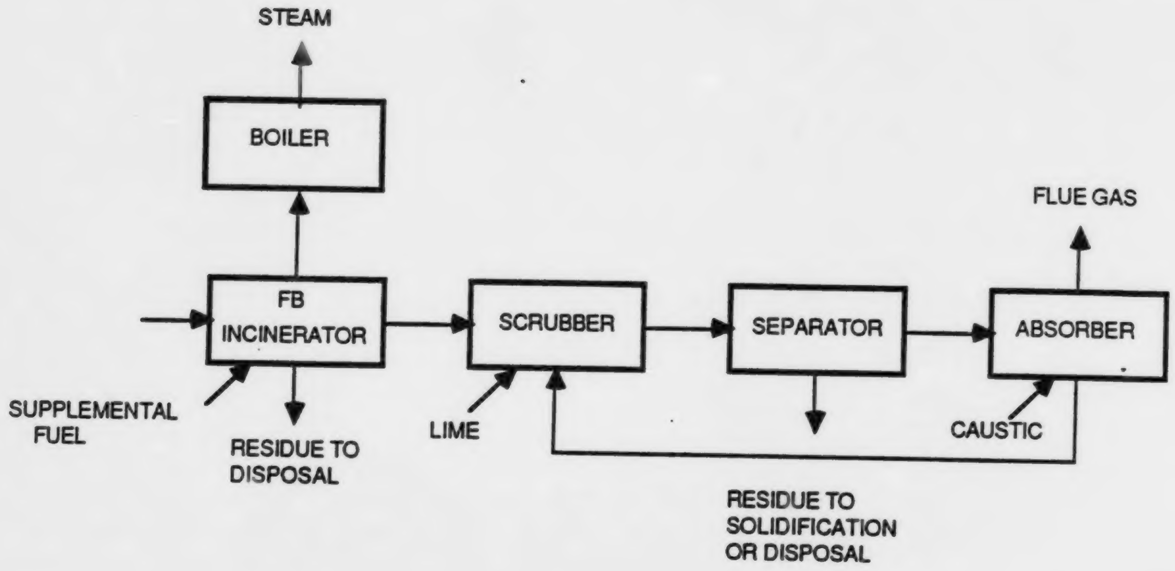
Fluidized bed incineration takes place in a heated bed of sand, through which the wastes and air are blown. As the air and combustion products rise through the sand bed, the particles are "fluidized" or floated. This configuration has several inherent advantages due to the extremely high rates of heat transfer with fluidized beds and the homogeneity of the fluidized bed incinerator. This technique is applicable to broad ranges of wastes, although there are two significant restrictions: (1) no bulk solids can be destroyed, and (2) only small quantities of chlorine and fluorine.(3) Fluidized bed systems have not yet been used in commercial hazardous waste facilities, although several have been used in large chemical complexes that achieve disposal of the range of organic wastes that is similar to those OWMC is expected to receive.(1)

Normal Operation

Under normal operating conditions fluidized bed incineration results in the release of steam and flue gases to the atmosphere. Although these flue gases are treated (see Figure C.30), they will contain traces of particulate and organic species. Other discharges from the fluidized bed incinerator are solidified in preparation for appropriate land disposal.

Special personal protective clothing and/or respirators may be required during maintenance since personnel may be exposed to solid residues containing hazardous substances. Protective equipment may

FIGURE C.30: FLUIDIZED BED INCINERATION



also be required for maintenance of the flue gas scrubbing system to protect against exposure to contaminants and caustic used in the process.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions if the scrubbing system for the flue gas fails. The off-site population may also be exposed in the event of large or highly dangerous air releases. Liquid spills will be contained on-site.

Types of Wastes Treatable (input flexibility)

Wastes in UCD categories 211-217, 221-228, 241-245, 247, 248, 252, 254, 257, 258, 261-264, 281-286, 288, 289, 416, 446, 447, 454, 455, 523, and 531 are potentially treatable using fluidized bed incineration. Chlorine content of the wastes must be less than 5% and fluorine less than 1,000 mg/l since wastes with higher chlorine and fluorine concentrations easily upset the process. Wastes consisting of viscous liquids or caking solids may be difficult to feed into the bed.(1)

Operational Flexibility (start-up and shut-down as needed)

Fluidized bed incinerators must be operated continuously due to the long time required to start up and shut down the process and to minimize thermal stressing of the incinerator refractories.

Unscheduled Downtime (operational reliability)

Because of the relative short history of fluidized bed incineration of hazardous wastes and the complexity of the operation, fluidized bed incinerators can be expected to have high (> 20%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Fluidized bed incinerators are complex in operation due to the number of process units used in the incineration and flue gas treatment system. While temperature is monitored automatically, a high level of operator skill is necessary. Periodic stack sampling is required to ensure adequate destruction and removal efficiency.

Cost

Fluidized bed incinerators are relatively expensive. For a system with a capacity of 30,000 tonnes per year, an operating cost of roughly $95 per tonne results.

LIQUID INJECTION INCINERATION (1,3,4,44,45,46,47)

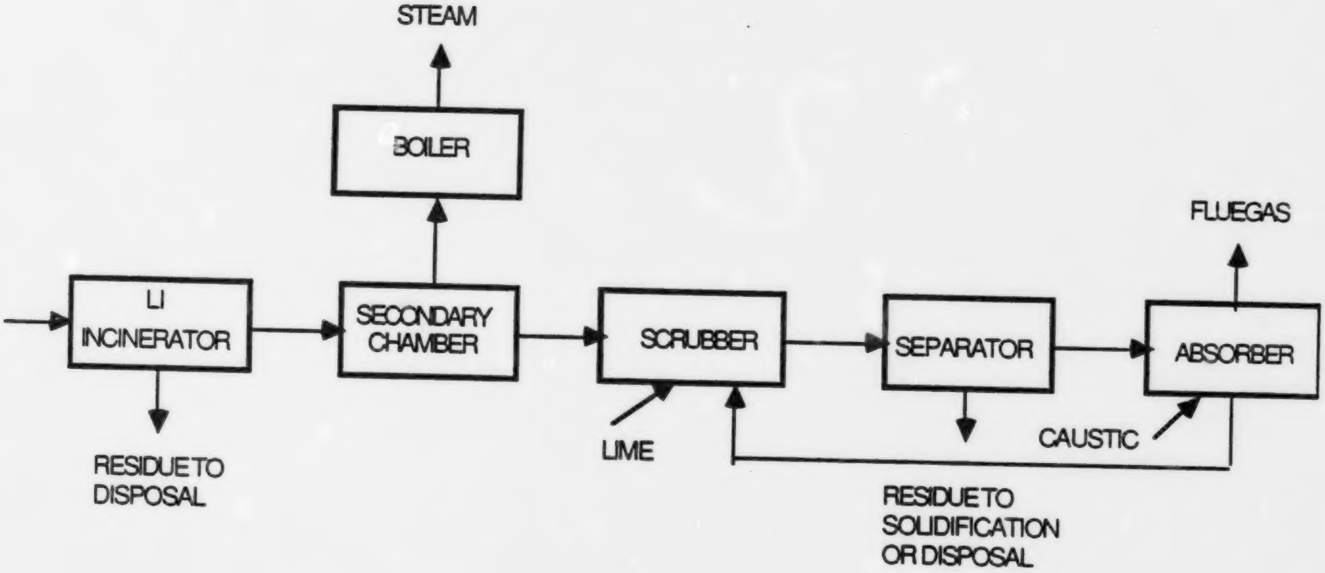
Process Description

Liquid injection incineration, as the name implies, is only applicable to the burning of liquids. The incineration system consists of a burner and fixed refractory chamber. Associated equipment includes feeders, air pollution control and, in many cases, heat recovery boilers.

Normal Operations

A liquid injection incineration train is illustrated in Figure C.31. As this figure shows, liquid injection incineration results in the release of treated flue gas to the atmosphere. The other streams leaving liquid injection incinerator trains are the residue resulting from the flue gas scrubber and, in some cases, slag; the scrubber residue would be solidified and landfilled. Thus, under normal operating conditions, the only uncontrolled releases to the environment are low levels of contaminants in the air that were not removed by the flue gas scrubbing system..

FIGURE C.31: LIQUID INJECTION INCINERATION



Special personal protective equipment (clothing and/or respirators) may be required during maintenance to protect against solid residuals that may have accumulated in the combustion chambers or the flue gas treatment system.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions in the event of a failure of the flue gas treatment system. Uncontrolled releases of inadequately incinerated stack gas may affect the off-site population but the quantity of such uncontrolled releases from the stack are likely to be small since gaseous emissions are routinely monitored and the process can be shut down quickly if air emissions exceed regulatory limits. Any liquid spills will be contained on-site.

Types of Wastes Treatable (input flexibility)

Liquid injection incineration can be used to treat wastes in UCD categories 213, 216, 217, 222, 223, 224, 225, 226, 227, 228, 242, and 281. Organic liquids that contain metals can clog the liquid injection nozzles and hence may be unsuitable for treatment. In general, liquid injection incineration is not easily upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Because liquid injection incinerators do not require the long times for start-up and shut-down that other incinerators do, they can be operated in a semi-continuous mode.

Unscheduled Downtime (operational reliability)

Liquid injection incinerators require less maintenance than any other type of incinerator because of the characteristics of the waste being burned and the fewer integral, hot moving parts when compared to other incineration techniques. They are the most widely used technology for incinerating liquid wastes. However, a number of process units are required, thus liquid injection incinerators have moderate (5-20%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Liquid injection incineration is complex in operation due to the number of process units involved and the number of parameters to be monitored. Operation often requires one or two trained personnel.(1) Automatic monitoring for temperature is performed.

Cost

A liquid injection incinerator with a capacity of 5,000 tonnes per year would have an operating cost of approximately $90 per tonne.

PYROLYSIS (1,3,4,44,45,46,47)

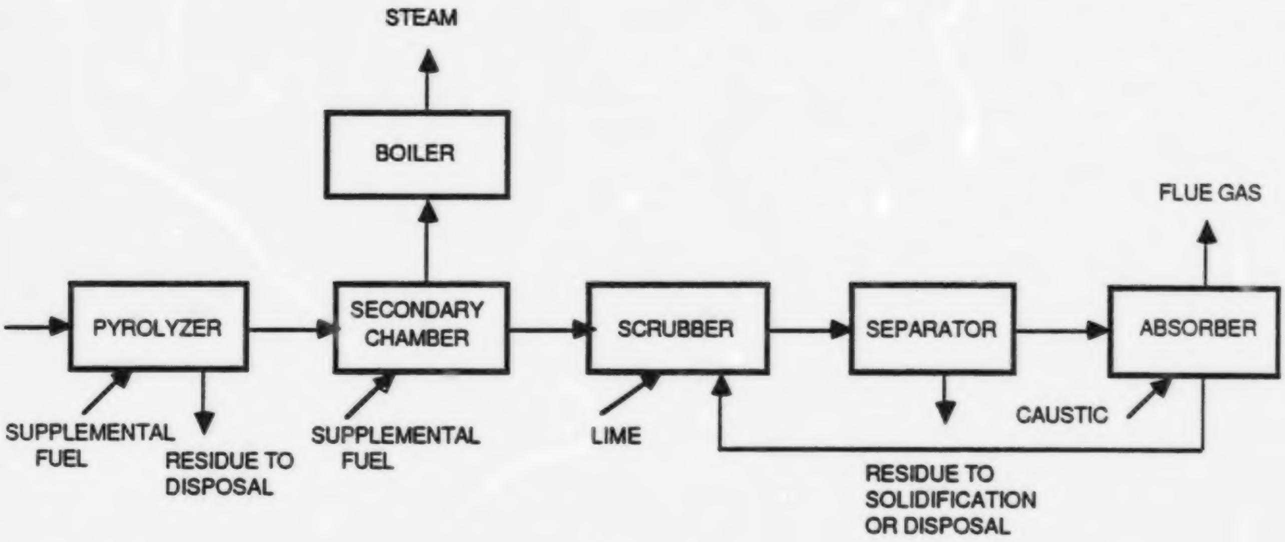
Process Description

Pyrolysis is a technique for decomposing organic waste at high temperatures with substoichiometric quantities of oxygen followed by burning the volatiles that are driven off in a secondary combustion chamber. The method is primarily for destruction of waste within a plant or complex. They have found little use in commercial facilities because of the relatively narrow range of wastes that can be treated. Pyrolysis units may also incorporate steam recovery.

Normal Operations

Pyrolysis systems, like other thermal processes, result in the release of a treated flue gas to the atmosphere, as shown in Figure C.32. There is also solid residue resulting from the scrubbing system. Pyrolysis has an additional waste stream of solid residue from the pyrolyzer.

FIGURE C.32: PYROLYSIS



Special personal protective equipment (clothing and/or respirators) may be required for maintenance to protect against hazardous solid residues in the pyrolizer and flue gas treatment system.

Abnormal Events

On-site personnel might be exposed to uncontrolled gaseous emissions in the event the pyrolyzer failed catastrophically. Uncontrolled releases of inadequately incinerated stack gas may affect the off-site population but are the quantity of such uncontrolled releases from the stack are likely to be small since gaseous emissions are routinely monitored and the process can be shut down quickly if air emissions exceed regulatory limits. Such emissions could be caused by a failure in the flue gas scrubbing system, or products of incomplete combustion that are not captured by the scrubber. Any liquid spills will be contained on-site.

Types of Wastes Treatable (input flexibility)

Some wastes from UCD categories 247, 248, 252, 257, 261, 263, 264, 282, 284, 285, 286, 288, 446, 447, 454, 455, 523 and 531 can be treated using pyrolysis. Pyrolysis systems are not easily upset by minor constituents, although high sodium wastes may degrade the refractory lining.

Operational Flexibility (start up and shut-down as needed)

Pyrolysis systems must be operated continuously because of the long time required for start-up and shut-down and to reduce the deterioration of the refractory materials.

Unscheduled Downtime (operational reliability)

Due to the number of process units involved (see Figure C.32) and the relatively few installations of pyrolyzers for the treatment of hazardous wastes, pyrolysis systems can be expected to have high (>20%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Pyrolysis systems are complex in operation for the same reasons as the other thermal treatment technologies. Automatic monitoring of temperature is performed.

Cost

A pyrolysis system with a capacity of 17,000 tonnes per year has an operating cost of approximately $95 per tonne.

ROTARY KILN INCINERATION (1,3,4,44,45,46,47,50)

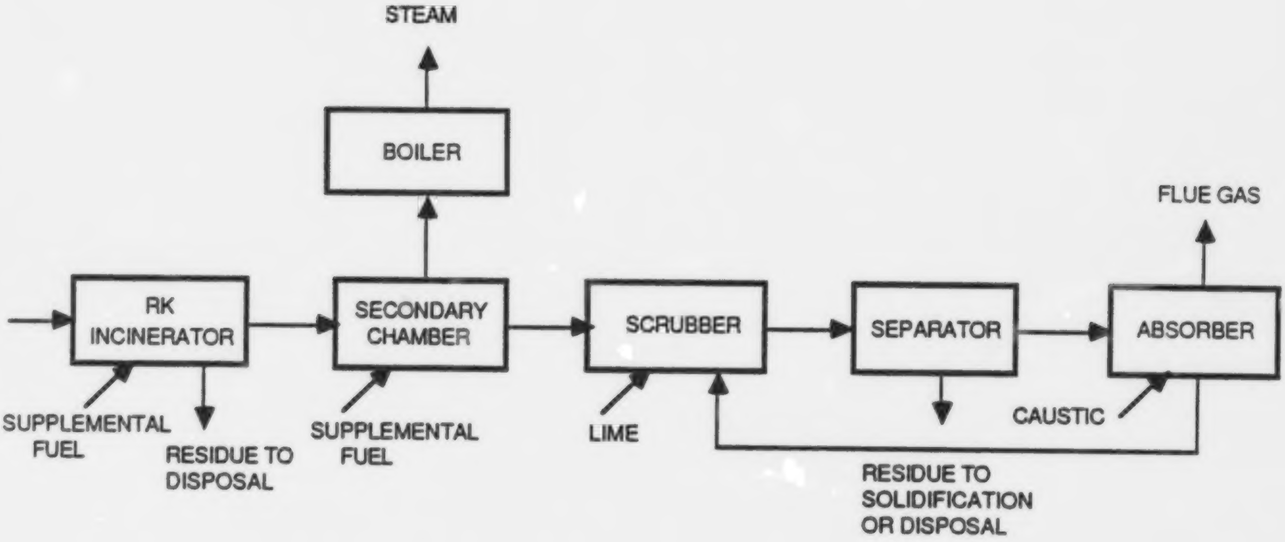
Process Description

Rotary kiln incineration consists of a two-part combustion system. The primary combustion chamber is the rotary kiln itself, a rolling cylinder that can be heated to over 1000°C. A secondary combustion chamber ensures that all burnable materials are destroyed. Rotary kiln incineration is used for burning all types of organic waste. The system is most frequently used in commercial facilities for incineration of hazardous or special waste because it has broad applicability to virtually all organic waste, independent of composition or form (bulk solid, containerized solid, sludge or liquid).

Normal Operations

Waste streams for rotary kiln incineration, shown in Figure C.33, are similar in type to those for pyrolysis. A treated flue gas is vented to the atmosphere and residue results from the flue gas scrubbing system. There is also a solid residue from the rotary kiln incinerator itself. There are uncontrolled releases to the environment associated with products of incomplete combustion that are not captured by the scrubbing system.

FIGURE C.33: ROTARY KILN INCINERATION



Special personal protective equipment (clothing and/or respirators) may be required for maintenance to prevent exposure to solid residues in the incinerator itself or in the flue gas treatment system.

Abnormal Events

On-site personnel may be exposed to uncontrolled gaseous emissions in the event of a failure of the flue gas treatment system. Uncontrolled releases of inadequately incinerated stack gas may affect the off-site population but the quantity of such uncontrolled releases from the stack are likely to be small since gaseous emissions are routinely monitored and the process can be shut down quickly if air emissions exceed regulatory limits. Any liquid spills will be contained on-site. Seal ring wear at the end of the rotary kiln may occur causing significant operational difficulty(3) and release waste to the plant environment that is incompletely treated. Several explosions have occurred in rotary kiln incinerators causing some damage to equipment.

Types of Wastes Treatable (input flexibility)

Waste in UCD categories 211-217, 221-228, 241-243, 244, 245, 247, 248, 251, 252, 254, 257, 258, 261-264, 281-286, 288, 289, 416, 446, 447, 454, 455, 512, 513, 521, 523, 528, 531 and 532 are treatable using rotary kiln incineration. Wastes high in sodium or fluorine can cause refractory corrosion and wear. It is important that the waste be blended, as required, to have a consistent heating value to avoid hot spots or flame-out. Otherwise, rotary kiln incinerators are not easily upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Rotary kiln incinerators must be operated continuously due to the time required for start-up and shut-down; frequent kiln start-ups is a major factor in premature refractory degradation.

Unscheduled Downtime (operational reliability)

Because rotary kiln incinerators consist of six major pieces of equipment in series (rotary kiln, secondary combustion chamber, waste heat boiler (optional), quench, scrubber, adsorber), as well as auxiliary equipment, the potential for failure is large, compared to liquid injection incineration. Thus, high (> 20%) unscheduled downtime can be expected. Significant process upsets such as loss of feed, fan failures, air pollution control failures or power outages may occur as many as ten to twenty times per year.

Ease of Operation and Monitoring (technical reliability)

Rotary kiln incineration is complex in operation because of the large number of process units. Incinerator designs incorporate automatic and continuous control to a large extent, including the monitoring of temperature. However, the operator still must monitor the operations periodically because visual checks and operator "art" are required.

Cost

A rotary kiln incineration system with a capacity of 36,000 tonnes per year would have an operating cost of approximately $105 per tonne, ignoring any credit for steam that may be generated in the process.

SOLIDIFICATION/STABILIZATION PROCESSES

Solidification/stabilization processes are used to convert treated inorganic wastes into solid products which leach more slowly and generally produce a less hazardous leachate than when the solidified. The waste is mixed with a cement-based, silicate based and/or lime based material (Portland Cement or sodium silicate, for example) to form the solid product.

Wastes treatable by solidification include residues and treated effluents from physical/chemical treatment processes and boiler ash, fly ash and salts from incineration.

The only waste stream from solidification/stabilization processes is the solid itself, which is landfilled.

SOLIDIFICATION/STABILIZATION PROCESSES (1,3,5,54,55,56)

Process Description

Solidification is a process where waste or waste residues are mixed with chemical reagents such as Portland cement, lime or sodium silicate to form stable solids. The objective of the process is to produce an environmentally safe material which is both physically and chemically resistant to leaching or migration under the environmental conditions expected at the engineered landfill. These conditions include the rainfall and water permeation into the landfill, temperature variations and freeze/thaw cycle, and any effects of biological organisms.

Normal Operation

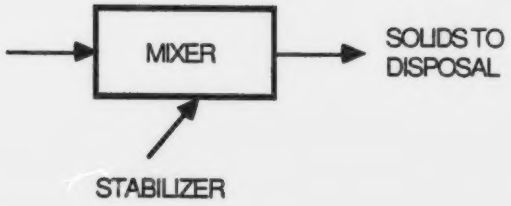
The only discharge stream from solidification is the solids that are then disposed of. There are no uncontrolled releases to the environment with a properly operating system, as shown in Figure C.34. However, the cement, lime, or sodium silicate must be handled properly as must be the solidified material to prevent dust releases.

Protective clothing and respirators may be required for solids handling the waste to protect against contact with the contaminants.

Abnormal Events

On-site personnel may be exposed in the event of a spill. Spills will be contained on-site and will not affect the surrounding

FIGURE C.34: SOLIFICATION/STABILIZATION



population or environment. Air releases from solidification involving lime or cement dust (which are relatively nonhazardous) are likely to be small, and confined to the plant site.

Types of Waste Treatable (input flexibility)

Residues from waste from UCD categories 141, 142, 145, 151, 152, 165, 167, 417, 431, 433, 441, 443, 444, 445, 454, 455 and 518 can be solidified, after being treated as completely as practical. The solidification process is easily upset by organics and for this reason wastes with greater than 10%-20% organics are not generally recommended for treatment.(1) Certain salts such as halides and sulfates may retard settling of the cement.(1) Pretreatment prior to solidification must remove cyanides. Chromium, cadmium and selenium can cause difficulties in some cases.(3)

Operational Flexibility (start up and shut-down as needed)

Solidification is operated as a batch process.

Unscheduled Downtime (operational reliability)

Because the equipment required for solidification is simple and the process well established,(1) solidification systems can be expected to have low unscheduled (<5%) downtime.

Ease of Operation and Monitoring (technical reliability)

Solidification is simple in operation involving only one process unit and related conveyors (see Figure C.34). Periodic monitoring for slump (ease with which the unsettled concrete can be compacted) and leachability must be performed.

Cost

A solidification system capable of treating 50,000 tonnes per year would have an operating cost of approximately $35 per tonne.

DISPOSAL PROCESSES

Disposal processes are designed to isolate wastes from the living environment. Wastes are placed either underground as in landfills, deep-well injection and geologic isolation, or above ground in warehouse storage. Except for deep-well injection, which is applicable to treated liquids, all of the disposal options handle only solid wastes. These include solid special wastes, treatment residues, and solidified wastes.

In theory, there are no uncontrolled releases of wastes to the environment from disposal processes. Secure engineered landfills have a history of liner failures, however, which can lead to groundwater contamination. Off-site permeation through rock layers in deep-well injection could also allow wastes to re-enter the environment.

DEEP-WELL INJECTION (1,3,5,51,52)

Process Description

Deep-well injection involves the disposal of pumpable wastes below the ground to depths ranging from 300-3,600 meters. Wastes are usually pretreated to remove large solids that could potentially clog the injection pumps. Deep-well injection has been identified as an avenue for potential contamination of fresh water aquifers but may have an application in areas where the receiving aquifer is already highly contaminated and is of little or no value. Deep-well injection is an alternative to solidification of liquid effluent.

Normal Operations

Under normal operations deep-well injection results in no uncontrolled releases to the environment. As shown in Figure C.35, the deep-well is the repository of the waste stream, and there are no other effluents.

No special personal protective equipment is required of operating personnel.

Abnormal Events

Failure of the well head or pump may expose on-site personnel to the waste being injected. Off-site, the possibility exists of groundwater contamination due to a failure in the formation into which the wastes are being injected. If insufficient pressure is maintained in the injection zone after well closure, the backflow of waste to the surface or adjacent strata may occur.(3) Liquid spills at the surface can be contained on-site.

Types of Wastes Treatable (input flexibility)

Deep-well injection can receive no incoming UCD waste categories, as discussed. The process is not easily upset by minor constituents but pretreatment to remove suspended solids to separate immiscible liquids and to degasify liquids is frequently necessary.

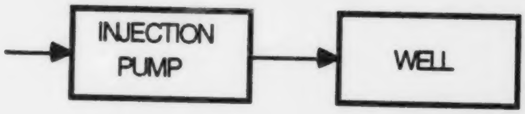
Operational Flexibility (start up and shut-down as needed)

Deep-well injection performs best when operated continuously but can be operated in a semi-continuous mode.

Unscheduled Downtime (operational reliability)

Deep-well injection has been used for over 30 years in the oil and gas industry to pump waste brine into deep strata.(1) Except for

FIGURE C.35: DEEP WELL INJECTION



the injection pump, few moving parts are involved, thus, deep-well injection can be expected to have low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Deep-well injection is relatively simple in operation since only one piece of process equipment is involved. Periodic monitoring of groundwater is required to ensure that waste remains in the injection strata.

Cost

A deep-well injection system capable of disposing of 20,000 tonnes per year would have an operating cost of approximately $15 per tonne.

GEOLOGIC ISOLATION (1,5)

Process Description

Geologic isolation in mined space involves placing special wastes in abandoned or newly constructed mines designed to receive and store the wastes indefinitely. Although the use of underground mine space for waste disposal has been extensively studied in both North America and Europe, experience with the technology has been limited to one facility in northwest Germany. There, wastes are stacked in containers in the open areas left by room and pillar construction in the mining operation. No liquid or ignitable wastes are accepted. Because strict operational safety measures are in practice, there have been no major accidents. Geologic isolation is generally restricted to wastes which cannot be adequately treated by other technologies.

Normal Operations

There are no uncontrolled releases to the environment under normal operating conditions with geologic isolation. As Figure C.36

FIGURE C.36: GEOLOGIC ISOLATION

shows, the wastes are disposed of in the underground caverns and there are no effluent streams.

Personal protective clothing and respirators are required for waste handling to prevent exposures from waste residues on the containers or in the event a container fails.

Abnormal Events

On-site personnel may be exposed to wastes in the event of a spill or accident. Exposure should be minimized by the use of protective equipment and a properly operating ventilation system will minimize any air exposure. The possibility also exists of a fire or explosion in the mined area. This problem would not exist, course, if flammable wastes were excluded from the disposal site, as they are in Germany. The off-site population and surrounding environment would not be affected by the operation since any liquid spills would be contained on-site and because the process has negligible air emissions.

Types of Wastes Treatable (input flexibility)

Geologic isolation can be used to dispose of wastes in UCD category 509. Because all wastes that are disposed of are containerized, the system is not upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Geologic isolation is operated as a batch process.

Unscheduled Downtime (operational reliability)

Because the only major equipment involved in geologic isolation is for transporting the containerized wastes or ventilating the mine, low (<5%) unscheduled downtime can be expected.

Ease of Operation and Monitoring (technical reliability)

Geologic isolation is simple in operation since little equipment is involved and the process merely involves the movement of containerized waste. Continuous monitoring of interior air, which requires operator support, is necessary to ensure a safe environment for operating personnel.

Cost

The geologic isolation disposal facility with a capacity of 50,000 tonnes per year is estimated to have an operating cost of $175 per tonne.

ENGINEERED LANDFILL (1,3,4,5,53)

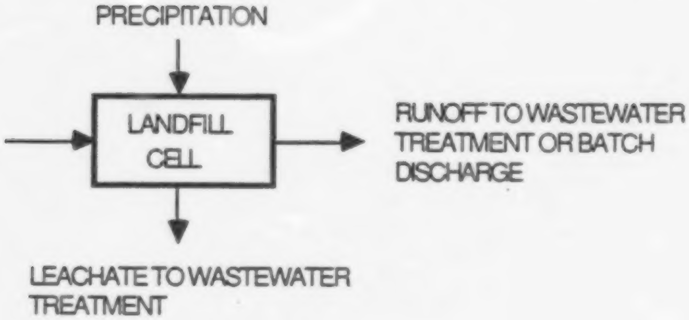
Process Description

An engineered landfill is a landfill where the waste is contained through application of engineered systems and materials. In a conventional landfill solidified material is placed in excavated cells or trenches and filling continues to form a mound above ground level. In aboveground landfills the solidified material is also placed in cells, but these are entirely above ground level. In a shallow entombed landfill, the solidified material is placed in excavations below ground level below the zone of active water flow in the near surface fractured clay. In OWMC's selected treatment and disposal scheme only solidified material will be placed in the landfill. No liquids and no untreated waste will be disposed of in the engineered landfill.

Normal Operation

A properly operated engineered landfill, as shown in Figure C.37, results in no uncontrolled emissions to the environment. Both leachate and runoff water from the landfill are treated prior to disposal. Since all waste will be solidified, there will be no air emissions problem.

FIGURE C:37: ENGINEERED LANDFILL


PRECIPITATION
LANDFILL CELL
RUNOFF TO WASTEWATER TREATMENT OR BATCH DISCHARGE
LEACHATE TO WASTEWATER TREATMENT

Protective clothing and respirators may be required for waste handling to prevent contact with the contaminants contained in the solidified material and inhalation of dust from the solid.

Abnormal Events

Possibility of exposure of on-site personnel to wastes should be minimized by the wearing of protective gear. The off-site population and surrounding environment may be contaminated during floods in excess of the design capacity of the landfill. Engineered landfills have had a history of liner failures. Groundwater contamination may result from failure of the landfill liner but on-site monitoring wells should detect any contamination in sufficient time to allow clean-up before groundwater outside the facility is affected.

Types of Wastes Treatable (input flexibility)

Waste in UCD category 509 can be landfilled once they are solidified as required.

Operational Flexibility (start up and shut-down as needed)

Engineered landfills are operated as batch processes.

Unscheduled Downtime (operational reliability)

Due to the simplicity of the operation, landfills can be expected to have low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Engineered landfilling is simple in operation since little equipment is involved. Periodic monitoring of groundwater is required to ensure liner integrity.

Cost

An engineered landfill with a capacity of 100,000 tonnes per year would have an operating cost of approximately $75 per tonne.

WAREHOUSE STORAGE (1)

Process Description

Warehouse storage refers to disposal of containerized special waste in specially designed aboveground buildings. Treated or solidified waste materials, for example, could be placed in drums and stacked on pallets in warehouse rooms. The drums would be carefully monitored and repaired or replaced as needed. Warehouse storage of treated special wastes differs very little from warehouse storage of chemicals or chemically-based products. The main difference is that waste must be carefully monitored and maintained indefinitely if the warehouse is used for final disposal.

Normal Operations

Under normal operating conditions warehouse storage results in no uncontrolled releases to the environment as shown in Figure C.38. As the warehouse is merely used as a repository of waste, there are no effluent streams.

Protective equipment (clothing and/or respirators) is required for waste handling to avoid contact with waste materials as could occur from container leaks or failures or simply from waste residues on the containers.

Abnormal Events

On-site personnel may be exposed in the event of a fire or explosion or in the event of the failure of the waste containers. The acceptance of only non-flammable waste would alleviate this problem,

FIGURE C.38: WAREHOUSE STORAGE

and routine use of protective clothing will minimize exposures due to container failures. The possibility also exists of the release of large quantities of contaminants during floods in excess of the design flood, which would also expose the surrounding environment and population. Proper design of the warehouse building is essential to ensure that the walls,floor and roof isolate the wastes from rainwater and can contain the waste within the building.(1)

Types of Wastes Treatable (input flexibility)

Waste in UCD category 509 are suitable to warehouse storage. As waste would be containerized there is no possibility of the process being upset by minor constituents.

Operational Flexibility (start up and shut-down as needed)

Warehouse storage is operated as a batch process.

Unscheduled Downtime (operational reliability)

Little long-term experience has been accumulated for the warehouse storage of wastes.(1) However, due to the simplicity of the operation, warehouse storage can be expected to have low (<5%) unscheduled downtime.

Ease of Operation and Monitoring (technical reliability)

Warehouse storage is simple in operation requiring little more than transportation and ventilation equipment. Interior air quality must be monitored continuously, requiring operator support to ensure a safe working environment.

Cost

Warehouse storage capacity of 50,000 tonnes per year would cost approximately $210 per tonne. Additional costs accrue for perpetual care but we are unable to quantify these.

APPENDIX D

TECHNOLOGY SCORING

APPENDIX D

TECHNOLOGY SCORING

The letter grades used in Chapters 3 and 4 to evaluate waste/technology combinations are based on numerical scores calculated using a ranking system developed to quantify how well each technology achieved OWMC's goals. This appendix provides further information on the technology scoring process, and is divided into five sections:

- Description of the Criteria.

- Description of the Ranking System.

- Rationale for Scoring Individual Technologies.

- Sensitivity Analysis of the Ranking System.

- Technology Summaries.

DESCRIPTION OF THE CRITERIA

The criteria used for technology evaluation are described on pages D-2 to D-10. Two types of criteria were used:

- Screening criteria
- Evaluation criteria

One screening criterion was used to eliminate from further consideration generic technologies which are unacceptable to OWMC. Only technologies which are proven according to OWMC's definitions were evaluated.

SCREENING CRITERION

1. Criterion: Proven

a. Definition: a proven technology has been commercially demonstrated to perform reliably for a period of at least 12 months on a scale and in a manner comparable with that required for the OWMC facility.

b. OWMC Goals Addressed:

I. Minimize risk to human health
II. Minimize impact on the environment
III. Minimize cost

c. Rationale/Significance:

A proven technology is more likely to perform as expected, so that risk to human health, impact on the environment, and cost can be assessed prior to selection. Performance of unproven technologies with respect to these goals cannot be predicted with sufficient confidence.

d. Measure:

Demonstrated for at least one commercial application

- length of use (yr)
- size of operation (capacity, throughput)
- wastes or materials handled (UCD numbers or description)

e. Scoring:

Unacceptable if there has been no commercial application for at least 12 months with a capacity or throughput, and with wastes or materials handled, that is comparable to expected OWMC use.

f. Comments/Assumptions/Limitations:

- if a technology is in commercial use it is assumed to perform reliably. Serious performance problems and mitigation measures should be noted where applicable.
- the difference in scale and waste or materials handled which is considered comparable varies depending on the technology.

g. Sources of Information:

- contacts with users, vendors, and regulatory agencies
- literature

RANKING CRITERIA

1. Criterion: Minimize Consequences of Abnormal Events

   a. Definition: An abnormal event is a circumstance which is not a part of normal operation (including process failures, accidents, vandalism and acts of God) which can result in an uncontrolled release of potentially hazardous materials. The consequences of abnormal events should be minimized.

   b. OWMC Goals Addressed:

      I. Minimize risk to human health
      II. Minimize impact on the environment

   c. Rationale/Significance:

   Abnormal events such as air inversions, fires or floods cannot be avoided; however, through careful planning and design the consequences of such events can be minimized. Technologies will be rated according to whether uncontrolled releases to the environment can be prevented, mitigated or ameliorated.

   d. Measure:

   - credible abnormal events (description, based on professional judgement)
   - characterization of uncontrolled releases from credible abnormal events given best available safety features and site assumptions

   e. Scoring:

	Excellent	Good	Fair
Onsite releases	Preventable	small release	Large release
Onsite human health consequences	None	-	Some probability of serious consequences
Off-site releases	Preventable	small release	Large release

e. Scoring: (continued)

	Excellent	Good	Fair
Off-site human health consequences	None	-	Some probability of serious consequences

f. Comments/Assumptions/Limitations:

- credible abnormal events will be defined based on a qualitative assessment of probability of occurrance of various types of events.

g. Sources of Information:

- risk assessments from related activities
- hazard and operability analyses

2. Criterion: Minimize Effects of Normal Operations

a. Definition: effects of normal operations addresses the potential impact of an option on the environment and human health near the facility, and on human health at the facility under normal operating conditions.

b. OWMC Goals Addressed:

I. Minimize risk to human health
II. Minimize impact on the environment

c. Rationale/Significance:

Different options will have different influences on human health and the environment. This influence will depend on many factors, including nature of the wastes handled, volume of emissions, exposure pathways, and offsite conditions. Options with no emissions beyond facility boundaries are preferred to options with any type of emissions. Options which minimize onsite risks to human health are preferred. A higher risk is associated with the amount of specialized safety equipment required to meet worker safety standards.

d. Measure:

- discharge pathways (list)
- special equipment required to meet worker safety standards (list)

e. Scoring:

	Excellent	Good	Fair
Discharges	none	batch	continuous
Special Equipment Required	none	monitoring	personal protective

f. Comments/Assumptions/Limitations:

- No simple model is available to address offsite effects more thoroughly in the technology evaluation process.

g. Sources of Information:

- flow diagram
- contacts with users, vendors, and regulatory agencies
- Ontario worker health and safety standards

3. Criterion: Maximize Operational Reliability

a. Definition: operational reliability addresses the ability to remain in operation and perform as expected.

b. OWMC Goals Addressed:

I. Minimize risk to human health
III. Minimize cost

c. Rationale/Significance:

When a technology is down for unscheduled repair wastes which would normally be handled by that technology must be stored. If the technology is an integral part of the system, other technologies may need to be shut down as well. Unscheduled temporary storage of waste may increase risk to onsite workers and would increase costs due to additional materials handling. Duplicate equipment may be required for technologies which need frequent maintenance.

d. Measure:

unscheduled downtime
(percent of total operation time)

e. Scoring:

	Excellent	Good	Fair
Amount of unscheduled downtime	0-5%	5-20%	More than 20%

f. Comments/Assumptions/Limitations:

None

g. Sources of Information:

- operational experience
- engineering judgement

4. Criterion: Maximize Technical Reliability

a. Definition: a technically reliable option will be relatively simple to operate providing minimium opportunity for either human or mechanical failure

b. OWMC Goals Addressed:

I. Minimize risk to human health
II. Minimize impact on the environment

c. Rationale/Significance:

Equipment failure and human error at a hazardous waste management facility may result in uncontrolled releases. It is therefore desirable to utilize options which are simple and consist of relatively few components.

d. Measure:

- ease of operation (simple, moderately complex, highly complex)
- monitoring and control of key variables (automatic, continuous with operator support, periodic)

e. Scoring:

	Excellent	Good	Fair
Ease of Operation	Simple	Moderately complex	Complex
Monitoring	Automatic	Continuous with operator support	Periodic

f. Comments/Assumptions/Limitations:

- if there is no need for monitoring, option is scored same as automatic monitoring

g. Sources of Information:

- operational experience
- engineering judgement

5. Criterion: Maximize Input Flexibility

a. Definition: input flexibility addresses the range of waste composition which can be handled without loss of effectiveness

b. OWMC Goals Addressed:

I. Minimize risk to human health
II. Minimize impact on the environment
III. Minimize cost

c. Rationale/Significance:

Use of technologies with higher input flexibility helps minimize the number of technologies needed to handle Ontario's wastes, both present and future. A system with fewer technologies is more easily controlled and monitored, and therefore provides a higher degree of reliability. In addition, technologies with higher input flexibility are more likely to be able to effectively handle unanticipated waste streams, which also means higher degree of technology reliability and reduces the possibility that future system expansion may be required.

d. Measure:

- UCD numbers handled (list)
- significance of variations within a UCD class

e. Scoring:

	Excellent	Good	Faire
UCD Group input flexibility	all UCD classes	several/many UCD classes	few UCD classes
Sensitivity to variations in composition with UCD class	Not sensitive	-	Sensitive

f. Comments/Assumptions/Limitations:

- A UCD group consists of several UCD waste classes.

g. Sources of Information:

- operating experience
- engineering judgement

6. Criterion: Maximize Operational Flexibility

a. Definition: operational flexibility addresses the range of waste quantity which can be handled and the ability to operate on an as needed basis.

b. OWMC Goals Addressed:

III. Minimize cost

c. Rationale/Significance:

Options which can be operated in batch and can be adjusted for variations in waste quantity may be more cost-effective since operation corresponds to actual wastes received. Options which must be operated continuously or semi-continuously may be less cost-effective since operation depends on available rather than expected wastes.

d. Measure:

- waste quantity handled (range, as throughput)
- type of operation (batch, semi-continous, continuous)

e. Scoring:

	Excellent	Good	Fair
Type of Operation	Batch	Semi-continuous	Continuous

f. Comments/Assumptions/Limitations:

None

g. Sources of Information:

- operational experience
- engineering judgement

7. Criterion: Minimize Cost

a. Definition: the selected option should provide protection of human health and the environment at the least total cost to the Province and the users.

b. OWMC Goals Addressed:

III. Minimize cost

c. Rationale/Significance:

The people of Ontario should get the most cost effective facility.

d. Measure:

$CND/tonne processed assuming full capacity operation

e. Scoring:

	Excellent	Good	Fair
Cost	Less than half of intermediate	Intermediate	Over twice intermediate

f. Comments/Assumptions/Limitations:

- Operating costs are used at this stage of the evaluation since determining capital costs requires too many assumptions (e.g., size of the unit, capital recovery rate).
- Operating costs are estimated for a unit of typical size and design.

g. Sources of Information:

- contacts with vendors and users
- operating experience
- engineering judgement

The evaluation criteria more explicitly define OWMC's goals so that their achievement can be evaluated. Each criterion is defined in terms of measures which can be rated as excellent, good or fair according to the characteristics of the technology being evaluated.

DESCRIPTION OF THE RANKING SYSTEM

A standard analytical technique, known as Conjoint Analysis, was used to quantify the relative importance of the criteria and the measures used to describe them to OWMC. The results of the Conjoint Analysis are shown in Figures D.1 and D.2.

Figure D.1 displays the relative importance to OWMC of each of the evaluation criteria. Figure D.2 indicates, for each criterion measure, the relative desirability to OWMC of each of the three ratings (excellent, good, fair). The sum of the ratings for each measure is zero. What this means, essentially, is that in selecting from among a limited range of options, a decision-maker is really balancing pluses and minuses around his/her own point of indifference. The Conjoint Analysis algorithm defines this point of indifference as 0 and determines the value of "excellent," "good," and "fair" relative to this point. (A less sophisticated ranking system would assume that the value of excellent = 1, good = 0, and fair = -1.) For example, in selecting among the hypothetical technologies presented, one of the measures (sensitivity to variations in waste composition) used for the "Input Flexibility" criterion did not affect the selections made by OWMC staff. In other words, the staff proved indifferent to the sensitivity of a technology to changes in waste composition; for this measure, the relative ratings were "excellent" = "good" = "fair" = 0.

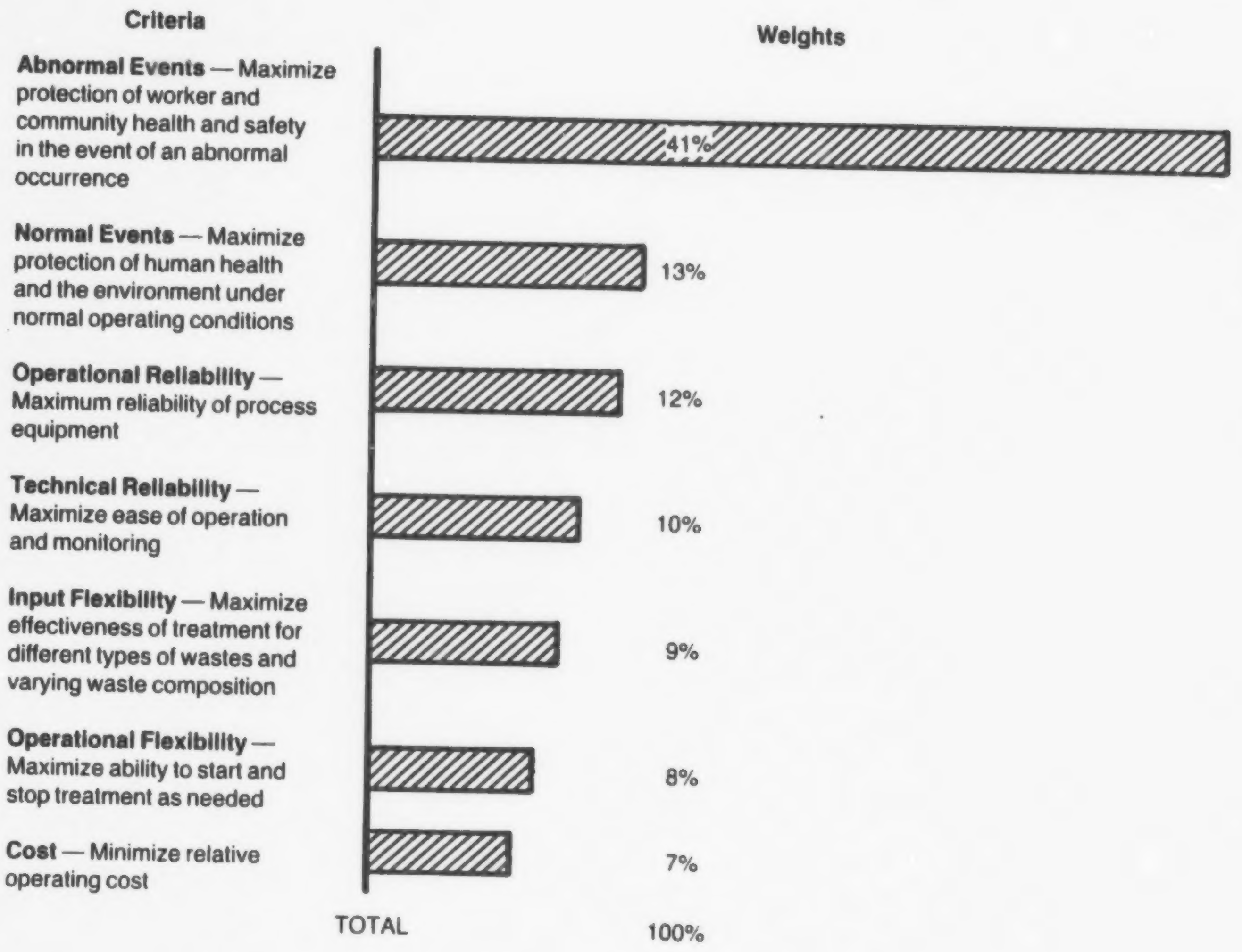


FIGURE D.1 RELATIVE IMPORTANCE OF CRITERIA TO OWMC

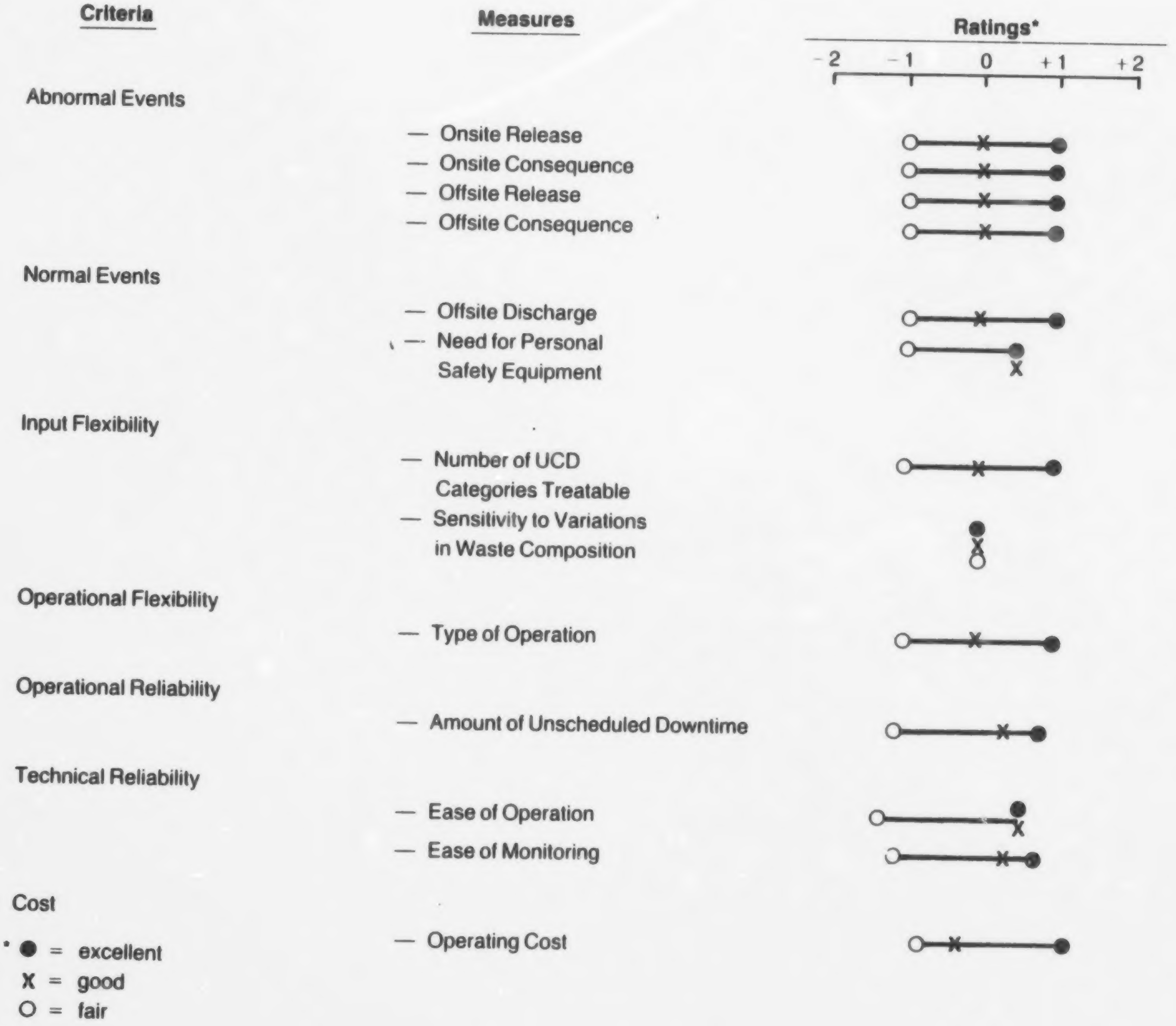


FIGURE D.2 COMPARISON OF EXCELLENT, GOOD AND FAIR RATINGS FOR EACH CRITERION MEASURE

The measures for abnormal events, off-site discharges during normal operations, range of waste types treatable and operational flexibility are symmetrically distributed around the point of indifference; i.e., "fair" = -1, "good" = 0, and "excellent" = +1. For unscheduled downtime, ease of operation, and ease of monitoring, both "good" and "excellent" characteristics were valued positively relative to the point of indifference. For operating costs, both "fair" and "good" characteristics were valued negatively relative to the point of indifference.

The information from Figures D.1 and D.2 was combined to yield a numerical score for each of the criteria measures (Table D.1). The scores given in Table D.1 have been scaled so that there are no negative scores and so that a technology which is excellent for every criterion receives a total score of 100.

The technologies were then evaluated by the criteria and assigned a score using Table D.1. A summary of the technology scores is given in Table D.2. The technology scores were converted to letter grades by the following scale:

A	82 - 100
A-	80 - 81
B+	78 - 79
B	62 - 77
B-	60 - 61
C+	58 - 59
C	less than 58

A "C" is used as the lowest grade to emphasize the fact that all of the technologies being evaluated are proven and acceptable; none of the evaluated technologies are unacceptable to OWMC.

TABLE D.1

CRITERIA SCORES

Criteria	Measures	Ratings Fair	 Good	 Excellent
Abnormal Events	On-site release	2	5	9
	On-site consequence	4	5	7
	Off-site release	0	5	11
	Off-site consequence	2	5	8
Normal Operation	Off-site discharge	4	5	7
	On-site special equipment	3	7	7
Input Flexibility	UCD group	2	5,6	8
	Variations	5	5	5
Operational Flexibility	Type of operation	3	5	8
Operational Reliability	Downtime	0	7	9
Technical Reliability	Ease of operation	4	6	6
	Monitoring	3	6	7
Cost	Operating cost	3	5	8
		34	72	100

Table D.2

SCORING SUMMARY

Technologies	abnormal events	normal events	input flexibility	operational flexibility	operational reliability	technical reliability	cost	TOTAL SCORE
BIOLOGICAL								
activated sludge	19	12	7	3	9	9	5	64
anaerobic digestion	19	8	10	3	7	9	5	61
fluid bed contactor	19	12	7	3	7	7	5	60
land treatment	8	7	11	8	9	9	3	55
activated sludge/ powdered act. carbon	19	12	7	3	9	9	5	64
rotating bio contact	19	12	7	3	7	9	5	62
trickling filter	19	12	7	3	7	7	5	60
waste stab. pond	8	11	7	8	9	9	3	55
PHYSICAL								
air stripping	19	12	7	8	9	9	8	72
carbon adsorption	28	12	7	8	9	9	3	76
resin adsorption	28	12	7	8	9	9	3	76
centrifugation	31	10	11	8	7	9	8	84
dissolved air float.	22	7	10	8	7	9	5	68
electrodialysis	31	12	10	8	0	12	8	81
emulsion breaking	22	14	10	8	9	9	5	77
evaporation	19	11	7	8	9	13	5	72
filtration	28	10	11	8	7	9	8	81
floc/sedimentation	28	14	11	8	7	9	3	80
reverse osmosis	31	12	10	8	0	12	8	81
solidification	31	10	11	8	9	9	3	81
solvent extraction	8	10	10	8	9	10	3	58
steam stripping	19	12	7	8	9	7	5	67
ultrafiltration	25	12	10	8	0	12	8	75
CHEMICAL								
chemical oxidation	8	8	10	8	9	7	5	55
chemical reduction	25	8	7	8	9	7	5	69
dehalogenation	8	10	7	8	9	7	3	52
ion exchange	31	12	11	8	9	12	8	91
precipitation	28	14	11	8	9	9	8	87
neutralization	28	14	7	8	9	13	8	87
wet air oxidation	8	11	11	3	0	11	8	52
THERMAL								
fluidized bed incin	8	7	11	3	0	11	5	45
liquid injection	8	7	11	5	7	11	5	54
pyrolysis	8	7	11	3	0	11	5	45
rotary kiln incin	8	7	12	3	0	11	5	46
DISPOSAL								
geologic isolation	25	10	11	8	9	12	3	78
deep well injection	8	14	11	5	7	9	8	62
engineered landfill	11	10	11	8	9	9	5	63
warehouse storage	8	10	11	8	9	12	3	61

RATIONALE FOR SCORING INDIVIDUAL TECHNOLOGIES

- Abnormal Events

A breakdown of the scoring for the criterion "Minimize Effect of Abnormal Events" is given in Table D.3. Specific rationale for the scoring based on abnormal events is summarized in Table D.4.

In scoring the technologies for abnormal events, the possibility and consequences of the following types of incidents were considered:

- Fire and explosion;
- Spills due to hose or line breaks, overfilling of tanks or tank/vessel failure,;
- Fugitive emissions;
- Process upsets;
- Flood or abnormal storm events;
- Air inversions;
- Liner and leachate collection system failure;
- Equipment failure;
- Failure of geologic formation; and
- Human error.

The types of incidents relevant to each technology were identified, and the possibilities for exposure by inhalation, ingestion, or direct contact were considered.

Table D.3

SCORING FOR ABNORMAL EVENTS OBJECTIVE

	onsite release	onsite consequences	offsite release	offsite consequences	total
Possible Scores					
excellent	9	7	11	8	
good	5	-	5	-	
fair	2	4	0	2	
Technologies					
BIOLOGICAL					
activated sludge	2	4	5	8	19
anaerobic digestion	2	4	5	8	19
fluid bed contactor	2	4	5	8	19
land treatment	2	4	0	2	8
activated sludge/ powdered act. carbon	2	4	5	8	19
rotating bio contact	2	4	5	8	19
trickling filter	2	4	5	8	19
waste stab. pond	2	4	0	2	8
PHYSICAL					
air stripping	2	4	5	8	19
carbon adsorption	2	7	11	8	28
resin adsorption	2	7	11	8	28
centrifugation	5	7	11	8	31
dissolved air flot.	2	7	5	8	22
electrodialysis	5	7	11	8	31
emulsion breaking	2	7	5	8	22
evaporation	2	4	5	8	19
filtration	2	7	11	8	28
floc/sedimentation	2	7	11	8	28
reverse osmosis	5	7	11	8	31
solidification	5	7	11	8	31
solvent extraction	2	4	0	2	8
steam stripping	2	4	5	8	19
ultrafiltration	5	7	5	8	25
CHEMICAL					
chemical oxidation	2	4	0	2	8
chromium reduction	2	4	11	8	25
dehalogenation	2	4	0	2	8
ion exchange	5	7	11	8	31
precipitation	2	7	11	8	28
neutralization	2	7	11	8	28
wet air oxidation	2	4	0	2	8
THERMAL					
fluidized bed incin	2	4	0	2	8
liquid injection	2	4	0	2	8
pyrolysis	2	4	0	2	8
rotary kiln incin	2	4	0	2	8
DISPOSAL					
geologic isolation	2	4	11	8	25
deep well injection	2	4	0	2	8
engineered landfill	2	7	0	2	11
warehouse storage	2	4	0	2	8

TABLE D.4

RATIONAL FOR ABNORMAL EVENTS SCORING

On-site Release and On-site Consequence

1. Undesirable for release; undesirable for consequences.

   a. Possibility of uncontrolled gaseous emissions; exposure to on-site personnel prior to emergency response:

      - Biological technologies
      - Air stripping
      - Evaporation
      - Dehalogenation
      - Chemical oxidation
      - Chromium reduction
      - Thermal technologies

   b. Possibility of fire or explosion; exposure to on-site personnel prior to emergency response:

      - Solvent extraction
      - Wet air oxidation
      - Geologic isolation (workers in contained area)
      - Warehouse storage (workers in contained area)

   c. Failure of well head or pump; exposure to on-site personnel prior to emergency response:

      - Deep-well injection

2. Undesirable for release; desirable for consequences.

   a. Possibility of large spill; contained without exposure:

      - Carbon adsorption
      - Dissolved air flotation
      - Filtration
      - Emulsion breaking
      - Flocculation/sedimentation
      - Precipitation
      - Neutralization

   b. Possibility of contact with waste; exposure prevented since workers already in protective gear:

      - Secure landfill

TABLE D.4 (continued)

3. Neutral for release; desirable for consequences.

   a. Possibility of small spill; contained without exposure:

      - Centrifugation
      - Electrodialysis
      - Reverse osmosis
      - Solidification
      - Ultrafiltration
      - Ion exchange

Off-site Release and Off-site Consequences

1. Undesirable for release; undesirable for consequences.

   a. Possibility of large or highly dangerous air release; exposure prior to emergency response:

      - Thermal technologies
      - Solvent extraction due to fire/explosion)
      - chemical oxidation
      - Dehalogenation
      - Wet air oxidation (due to fire/explosion)

   b. Possibility of release of large quantity of contaminants during flood in excess of design flood; exposure not preventable:

      - Land treatment
      - Waste stabilization ponds
      - Secure landfill
      - Warehouse storage

   c. Possibility of groundwater contamination; not detected by monitoring system:

      - Deep-well injection (formation failure)

2. Neutral for release, desirable for consequences.

   Possibility of small volume air release; no off-site exposure due to buffer zone, dilution and emergency response:

      - Air stripping
      - Dissolved air flotation
      - Emulsion breaking

TABLE D.4 (continued)

- Evaporation
- Steam stripping
- Ultrafiltration
- Biological technologies except waste stabilization ponds and land treatment

3. Desirable for release and consequences.

No air release; any liquid release is contained on-site:

- Carbon absorption
- Centrifugation
- Electrodialysis
- Filtration
- Floc/sedimentation
- Reverse osmosis
- Solidification
- Chromium reduction
- Ion exchange
- Precipitation
- Neutralization
- Geologic isolation

- Normal Operations

A breakdown of the scoring for the criterion "Minimize Effect of Normal Events" is given in Table D.5. Scores for the normal events criterion range from a low of 7 for the thermal technologies to a high of 14 for various treatment technologies. The off-site discharge measure is based on whether discharges to the environment are expected during normal operations. Streams which go to other treatment technologies are not considered to be off-site discharges. The lowest score is given to continuous discharges which cannot be easily controlled. Even if monitoring indicates that a discharge is above the environmental standards set for the facility and the system is shut down, some of the above standard emission would have escaped. The middle score is given to batch discharges which can be analyzed prior to discharge. While there is still a discharge to the environment, wastes which are above standards can be sent to further treatment prior to any discharge. Technologies which have no discharge received the highest score. This includes all of the disposal technologies and some of the chemical and physical treatment technologies.

Special equipment refers to the types of personal protective gear which are required in the normal operation of the facility including waste treatment and disposal, sampling, and equipment maintenance. The lowest score is given to technologies which require a respirator or special protective clothing for any of these procedures and the high score is given if a respirator or special clothing is not required at any time during normal operation. Respirators and/or special clothing are generally required for technologies which handle highly toxic materials, have uncontrolled volatile emissions or involve handling of solid waste or reagents.

Table D.5

SCORING FOR NORMAL EVENTS OBJECTIVE

	offsite discharge	special equipment	total	comments
Possible Scores				
excellent	7	7		none; none
good	5	7		batch discharge; safety monitoring
fair	4	3		continuous discharge; personal safety equipment (e.q. respirator)
Technologies				
BIOLOGICAL				
activated sludge	5	7	12	batch; none
anaerobic digestion	5	3	8	batch; supplied air during maintenance
fluid bed contactor	5	7	12	batch; none
land treatment	4	3	7	continuous; respirator
activated sludge/ powdered act. carbon	5	7	12	batch; none
rotating bio contact	5	7	12	batch; none
trickling filter	5	7	12	batch; none
waste stab. pond	4	7	11	continuous; none
PHYSICAL				
air stripping	5	7	12	batch; none
carbon adsorption	5	7	12	batch; none
resin adsorption	5	7	12	batch; none
centrifugation	7	3	10	none; protective clothing
dissolved air float.	4	3	7	continous; protective clothing
electrodialysis	5	7	12	batch; none
emulsion breaking	7	7	14	none; none
evaporation	4	7	11	continuous; none
filtration	7	3	10	none; protective clothing
floc/sedimentation	7	7	14	none; none
reverse osmosis	5	7	12	batch; none
solidification	7	3	10	none; protective clothing
solvent extraction	7	3	10	none; respirator during maintenance
steam stripping	5	7	12	batch; none
ultrafiltration	5	7	12	batch; none
CHEMICAL				
chemical oxidation	5	3	8	batch; protective clothing
chromium reduction	5	3	8	batch; protective clothing
dehalogenation	7	3	10	none; protective clothing
ion exchange	5	7	12	batch; none
precipitation	7	7	14	none; none
neutralization	7	7	14	none; none
wet air oxidation	4	7	11	continuous; none
THERMAL				
fluidized bed incin	4	3	7	continuous; respirator during maintenance
liquid injection	4	3	7	continuous; respirator during maintenance
pyrolysis	4	3	7	continuous; respirator during maintenance
rotary kiln incin	4	3	7	continuous; respirator during maintenance
DISPOSAL				
geologic isolation	7	3	10	none; protective clothing
deep well injection	7	7	14	none; none
engineered landfill	7	3	10	none; protective clothing
warehouse storage	7	3	10	none; protective clothing

- **Input Flexibility**

A breakdown of the scoring for the criterion "Maximize Input Flexibility" is given in Table D.6. Input flexibility measures the types of wastes which can be handled by a given technology. Scores for this criterion range from a low of 7 to a high of 12. No technology is given a perfect score since no technology can handle all possible wastes. The biological technologies are generally the most limited in terms of wastes handled, and thermal and disposal technologies are the most versatile.

All technologies score the same for the effect of variations within a waste class on technology performance because the Conjoint process results showed that this measure does not influence the technology selection process.

- **Operational Flexibility**

A breakdown of the scoring for the criterion "Maximize Operational Flexibility" is given in Table D.7. Operational flexibility measures the ability to schedule waste treatment as needed. The measure of flexibility is whether the treatment technology is, in order of preference, batch, semi-continuous, or continuous.

All of the physical technologies and most of the chemical and disposal technologies are batch processes. Many of the biological and thermal technologies must be operated continuously.

- **Operational Reliability**

A breakdown of the scoring for the criterion "Maximize Operational Reliability" is given in Table D.8. Operational reliability addresses the likelihood that the technology will not be available for use when it is needed. It is measured by the amount of downtime

Table D.6

SCORING FOR INPUT FLEXIBILITY OBJECTIVE

	UCD groups	variations within UCD class	total	comments
Possible Scores				
excellent	8	5		all UCD classes
good	5,6	-		several/many UCD classes
fair	2	5		one/few UCD classes
Technologies				
BIOLOGICAL				
activated sludge	2	5	7	few
anaerobic digestion	5	5	10	several
fluid bed contactor	2	5	7	few
land treatment	6	5	11	many
activated sludge/ powdered act. carbon	2	5	10	few
rotating bio contact	2	5	7	few
trickling filter	2	5	7	few
waste stab. pond	2	5	7	few
PHYSICAL				
air stripping	2	5	7	few
carbon adsorption	2	5	7	few
resin adsorption	2	5	7	few
centrifugation	6	5	11	many
dissolved air float.	5	5	10	several
electrodialysis	5	5	10	several
emulsion breaking	5	5	10	several
evaporation	2	5	7	few
filtration	6	5	11	many
floc/sedimentation	6	5	11	many
reverse osmosis	5	5	10	several
solidification	6	5	11	many
solvent extraction	5	5	10	several
steam stripping	2	5	7	few
ultrafiltration	5	5	10	several
CHEMICAL				
chemical oxidation	5	5	10	several
chromium reduction	2	5	7	few
dehalogenation	2	5	7	few
ion exchange	6	5	11	many
precipitation	6	5	11	many
neutralization	2	5	11	few
wet air oxidation	6	5	11	many
THERMAL				
fluidized bed incin	6	5	11	many
liquid injection	6	5	11	many
pyrolysis	6	5	11	many
rotary kiln incin	7	5	12	many (more than other thermal technologies)
DISPOSAL				
geologic isolation	6	5	11	many
deep well injection	6	5	11	many
engineered landfill	6	5	11	many
warehouse storage	6	5	11	many

Table D-7

SCORING FOR OPERATIONAL FLEXIBILITY OBJECTIVE

	type of operation	comments
Possible Scores		
excellent	8	batch
good	5	semi-continuous
fair	3	continuous
Technologies		
BIOLOGICAL		
activated sludge	3	continuous
anaerobic digestion	3	continuous
fluid bed contactor	3	continuous
land treatment	8	batch
activated sludge/ powdered act. carbon	3	continuous
rotating bio contact	3	continuous
trickling filter	3	continuous
waste stab. pond	8	batch
PHYSICAL		
air stripping	8	batch
carbon adsorption	8	batch
resin adsorption	8	batch
centrifugation	8	batch
dissolved air float.	8	batch
electrodialysis	8	batch
emulsion breaking	8	batch
evaporation	8	batch
filtration	8	batch
floc/sedimentation	8	batch
reverse osmosis	8	batch
solidification	8	batch
solvent extraction	8	batch
steam stripping	8	batch
ultrafiltration	8	batch
CHEMICAL		
chemical oxidation	8	batch
chromium reduction	8	batch
dehalogenation	8	batch
ion exchange	8	batch
precipitation	8	batch
neutralization	8	batch
wet air oxidation	3	continuous
THERMAL		
fluidized bed incin	3	continuous
liquid injection	5	semi-continuous
pyrolysis	3	continuous
rotary kiln incin	3	continuous
DISPOSAL		
geologic isolation	8	batch
deep well injection	5	semi-continuous
engineered landfill	8	batch
warehouse storage	8	batch

Table D-8

SCORING FOR OPERATIONAL RELIABILITY

	down time	comments
Possible Scores		
excellent	9	low (0-5%)
good	7	moderate (5-20%)
fair	0	high (over 20%)
Technologies		
BIOLOGICAL		
activated sludge	9	low
anaerobic digestion	7	moderate
fluid bed contactor	7	moderate
land treatment	9	low
activated sludge/ powdered act. carbon	9	low
rotating bio contact	7	moderate
trickling filter	7	moderate
waste stab. pond	9	low
PHYSICAL		
air stripping	9	low
carbon adsorption	9	low
resin adsorption	9	low
centrifugation	7	moderate
dissolved air float.	7	moderate
electrodialysis	0	high
emulsion breaking	9	low
evaporation	9	low
filtration	7	moderate
floc/sedimentation	7	moderate
reverse osmosis	0	high
solidification	9	low
solvent extraction	9	low
steam stripping	9	low
ultrafiltration	0	high
CHEMICAL		
chemical oxidation	9	low
chromium reduction	9	low
dehalogenation	9	low
ion exchange	9	low
precipitation	9	low
neutralization	9	low
wet air oxidation	0	high
THERMAL		
fluidized bed incin	0	high
liquid injection	7	moderate
pyrolysis	0	high
rotary kiln incin	0	high
DISPOSAL		
geologic isolation	9	low
deep well injection	7	moderate
engineered landfill	9	low
warehouse storage	9	low

expected. The highest score is given if the technology is almost always available when needed, the second highest score if the technology is down fairly often but not an unreasonable amount of time, and the lowest score if frequent down time is expected. A zero score is given for frequent downtime reflecting OWMC's concern that the technologies be available as needed.

- Technical Reliability

A breakdown of the scoring for the criterion "Maximize Technical Reliability" is given in Table D.9. Ease of operation and type of the monitoring and control system required are the measures of technical reliability. Technologies are assumed to be easier to operate if they incorporate fewer sequential or parallel operations and control parameters. Processes with automatic controls are assumed to be more reliable than those that rely on operator intervention for normal control, since many studies have shown that operator error is a major cause of accidents. If automatic controls are not tested frequently and monitored properly, errors can occur in the control loop, possibly causing unacceptable releases. The controls of interest in ranking the technologies for technical reliability are those which monitor or control a primary operating parameter or the quality of an effluent stream. The lowest score for this measure is given for technologies which depend on periodic monitoring. Technologies which can be monitored automatically receive the highest score. The technologies which are monitored continuously but require operator support receive a middle score.

- Cost

A breakdown of the scoring for the criterion "Minimize Cost" is given in Table D.10. The average operating cost ($/tonne) for each technology is compared to other technologies in the same categories. Technologies which cost half as much or twice as much as the intermediate unit cost are considered to be more desirable or less desirable, respectively.

Table D.9

SCORING FOR TECHNICAL RELIABILITY

	ease of operation	type of monitoring	total	comments
Possible Scores				
excellent	6	7		simple; automatic
good	6	6		moderately complex; continuous w/ operator support
fair	4	3		complex; periodic
Technologies				
BIOLOGICAL				
activated sludge	6	3	9	simple; periodic
anaerobic digestion	6	3	9	simple; periodic
fluid bed contactor	4	3	7	complex; periodic
land treatment	6	3	9	simple; periodic
activated sludge/ powdered act. carbon	6	3	9	simple; periodic
rotating bio contact	6	3	9	mod. complex; periodic
trickling filter	4	3	7	complex; periodic
waste stab. pond	6	3	9	simple; periodic
PHYSICAL				
air stripping	6	3	9	simple; periodic
carbon adsorption	6	3	9	simple; periodic
resin adsorption	6	3	9	simple; periodic
centrifugation	6	3	9	simple; periodic
dissolved air flot.	6	3	9	simple; periodic
electrodialysis	6	6	12	mod. complex; continuous w/ support
emulsion breaking	6	3	9	simple; periodic
evaporation	6	7	13	simple; automatic
filtration	6	3	9	mod. complex; periodic
floc/sedimentation	6	3	9	mod. complex; periodic
reverse osmosis	6	6	12	mod. complex; continuous w/ support
solidification	6	3	9	simple; periodic
solvent extraction	4	6	10	complex; continuous w/ support
steam stripping	4	3	7	complex; periodic
ultrafiltration	6	6	12	mod. complex; continuous w/ support
CHEMICAL				
chemical oxidation	4	3	7	complex; periodic
chromium reduction	4	3	7	complex; periodic
dehalogenation	4	3	7	complex; periodic
ion exchange	6	6	12	mod. complex; continuous w/ support
precipitation	6	3	9	simple; periodic
neutralization	6	7	13	simple; automatic
wet air oxidation	4	7	11	complex; automatic
THERMAL				
fluidized bed incin	4	7	11	complex; automatic
liquid injection	4	7	11	complex; automatic
pyrolysis	4	7	11	complex; automatic
rotary kiln incin	4	7	11	complex; automatic
DISPOSAL				
geologic isolation	6	6	12	mod. complex; continuous w/ support
deep well injection	6	3	9	mod. complex; periodic
engineered landfill	6	3	9	mod. complex; periodic
warehouse storage	6	6	12	mod. complex; continuous w/ support

Table D.10

SCORING FOR COST OBJECTIVE

	relative cost	unit cost ($/tonne)
Possible Scores		
excellent	8	half
good	5	middle
fair	3	twice
Technologies		
BIOLOGICAL		
activated sludge	5	15
anaerobic digestion	5	15
fluid bed contactor	5	15
land treatment	3	30
activated sludge/ powdered act. carbon	5	20
rotating bio contact	5	15
trickling filter	5	15
waste stab. pond	3	35
PHYSICAL		
air stripping	8	3
carbon adsorption	3	65
resin adsorption	3	85
centrifugation	8	2
dissolved air float.	5	20
electrodialysis	8	2
emulsion breaking	5	20
evaporation	5	20
filtration	8	2
floc/sedimentation	3	40
reverse osmosis	8	1
solidification	3	35
solvent extraction	3	75
steam stripping	5	10
ultrafiltration	8	2
CHEMICAL		
chemical oxidation	5	35
chromium reduction	5	35
dehalogenation	3	1000
ion exchange	8	5
precipitation	8	10
neutralization	8	10
wet air oxidation	8	15
THERMAL		
fluidized bed incin	5	95
liquid injection	5	90
pyrolysis	5	95
rotary kiln incin	5	105
DISPOSAL		
geologic isolation	3	175
deep well injection	8	15
engineered landfill	5	75
warehouse storage	3	210

SENSITIVITY OF THE SCORES TO THE RANKING SYSTEM

The purpose of the technology evaluation process was to design a system which best meets OWMC goals. The quantitative rankings provide a guide to the relative merits of the technologies available for treatment of particular types of wastes. Sensitivity analysis is used to determine the effect of various assumptions on the results obtained.

The analysis discussed below examines three elements:

- The effect of error in the Conjoint Analysis.
- The effect of individual criteria scores.
- The effect of weights.

• The Effect of Error in the Conjoint Analysis

The scores used in evaluating technologies were derived by Conjoint Analysis from a ranking of hypothetical technologies by OWMC decision-makers. The error introduced by the Conjoint Analysis method was determined by changing the ranking of each hypothetical technology by 1 (e.g., from 4 to 3 or 4 to 5) and recalculating the scores. Using this method, the overall error of the total score given for each technology was found to be ±4. Final technology scores with error bars are plotted for each treatment category in Figures D.3 and D.7.

The significance of the error is that technologies with overlapping error bars are not distinguished by the ranking system. Activated sludge/powdered activated carbon, for example, is the highest scoring biological treatment technology but is not significantly better than the next five biological technologies since their error bars overlap (Figure D.3). Activated sludge/powdered activated carbon, however, does have a significantly better score than land treatment and waste stabilization ponds since the error bars do not overlap.

Figure D.3

BIOLOGICAL TECHNOLOGIES

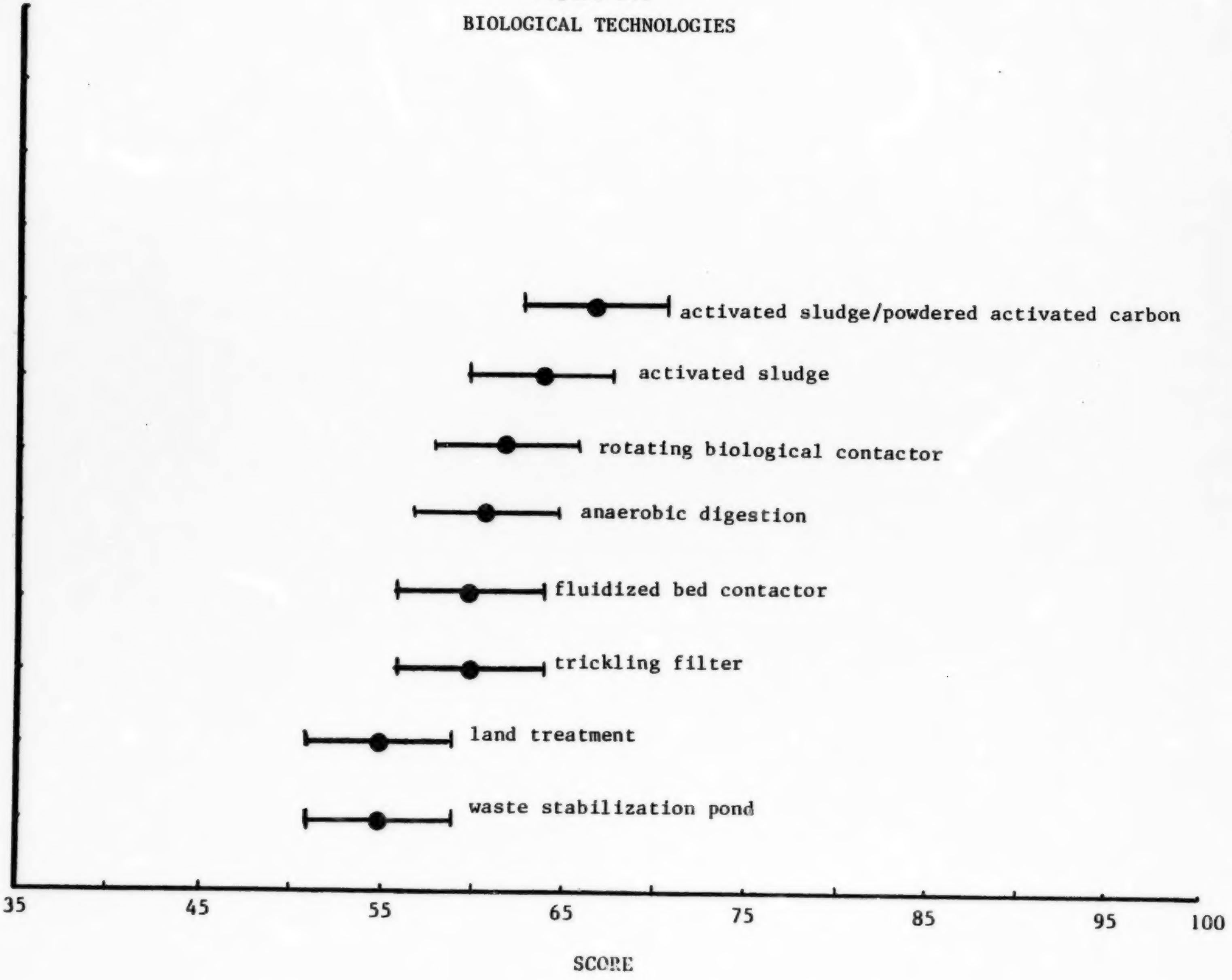


Figure D.4
PHYSICAL TECHNOLOGIES

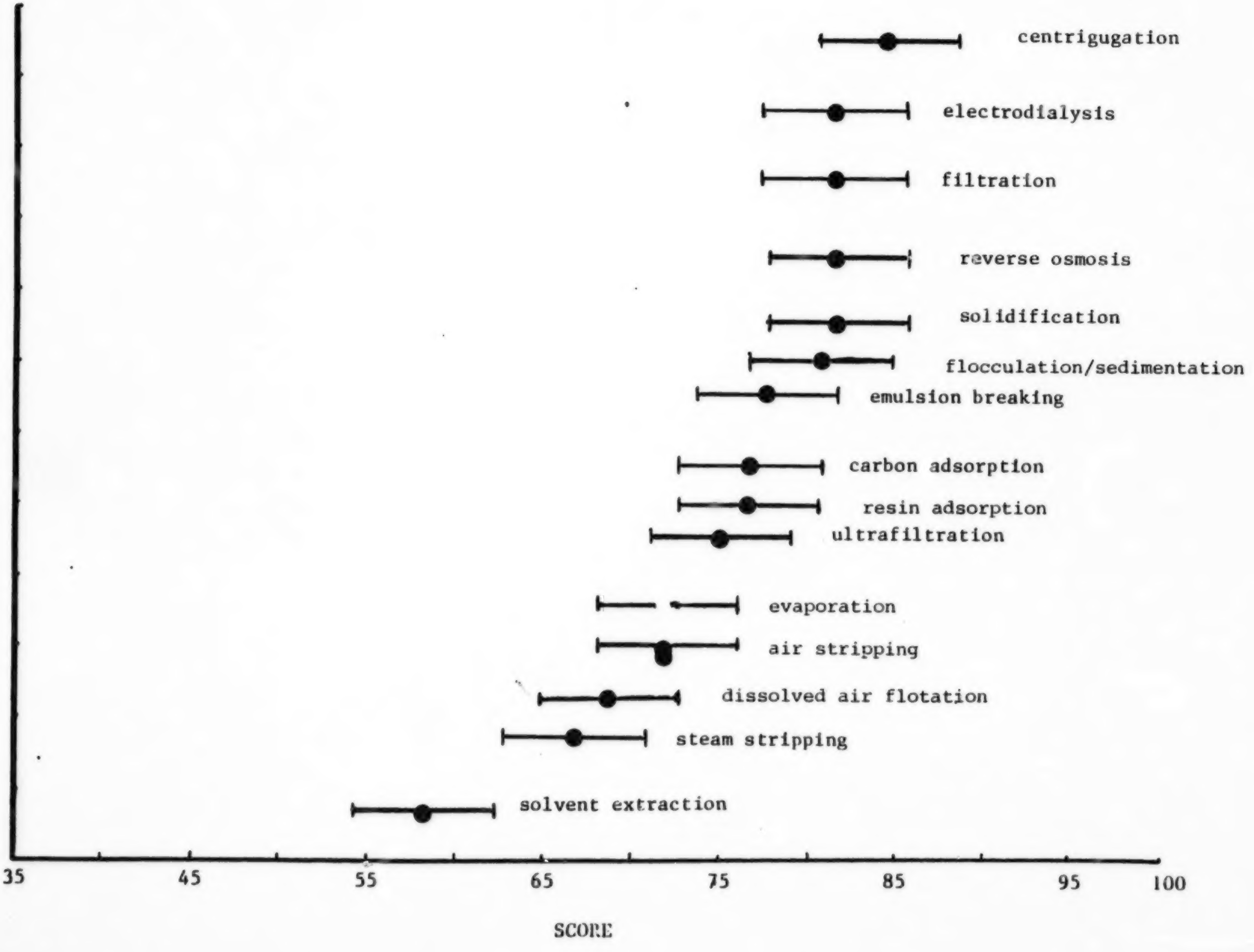


Figure D.5
CHEMICAL TECHNOLOGIES

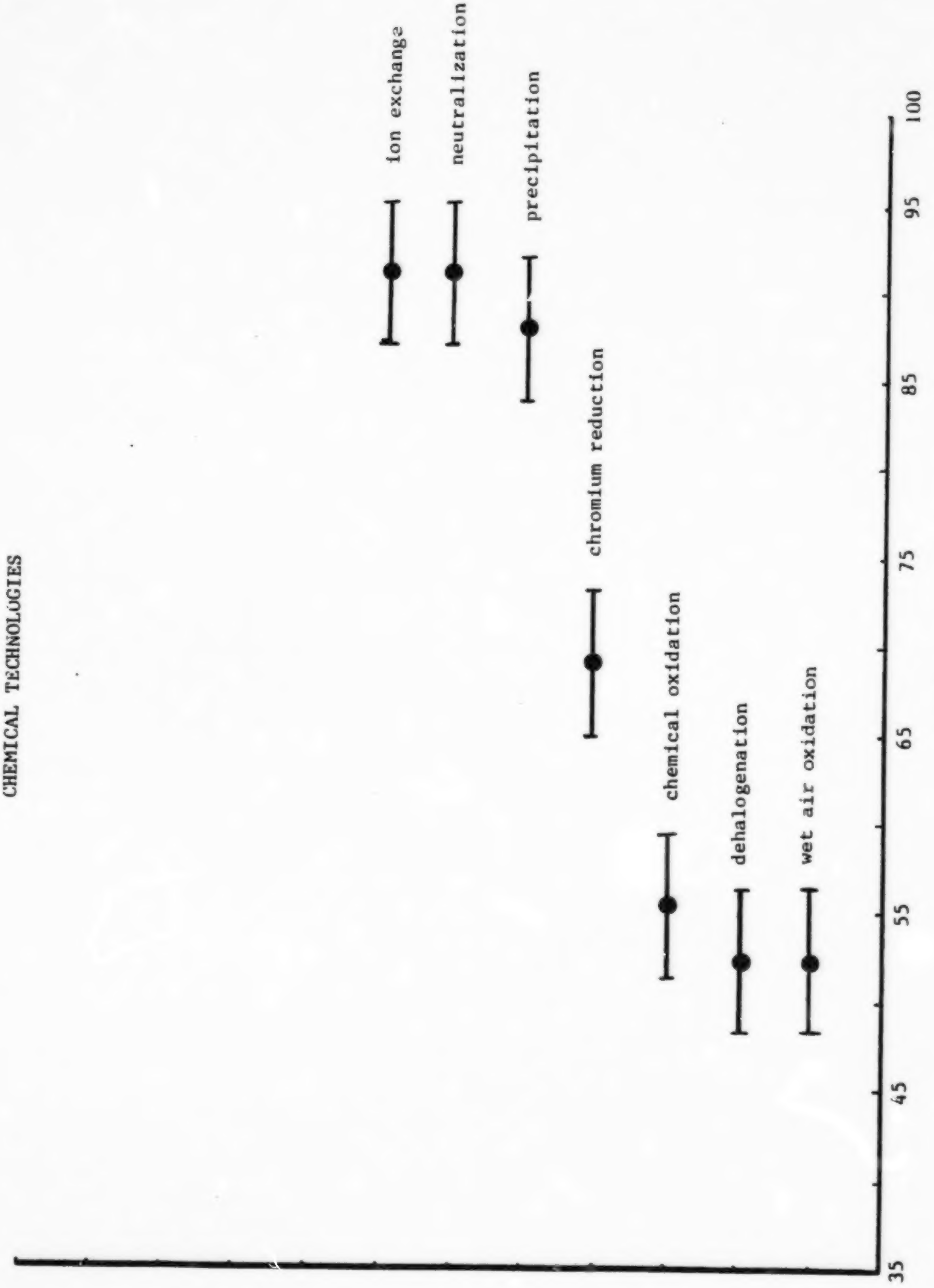


Figure D.6
THERMAL TECHNOLOGIES

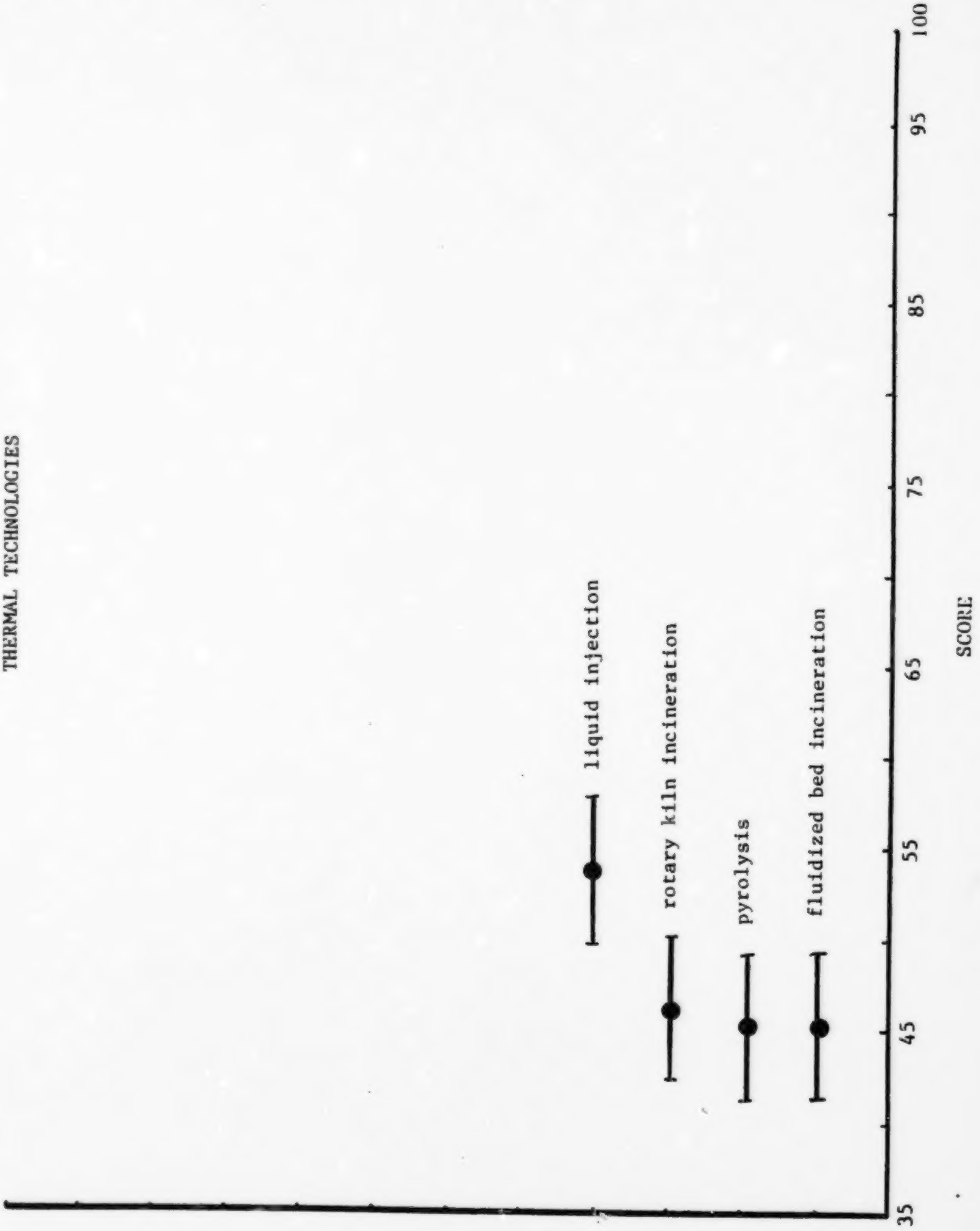
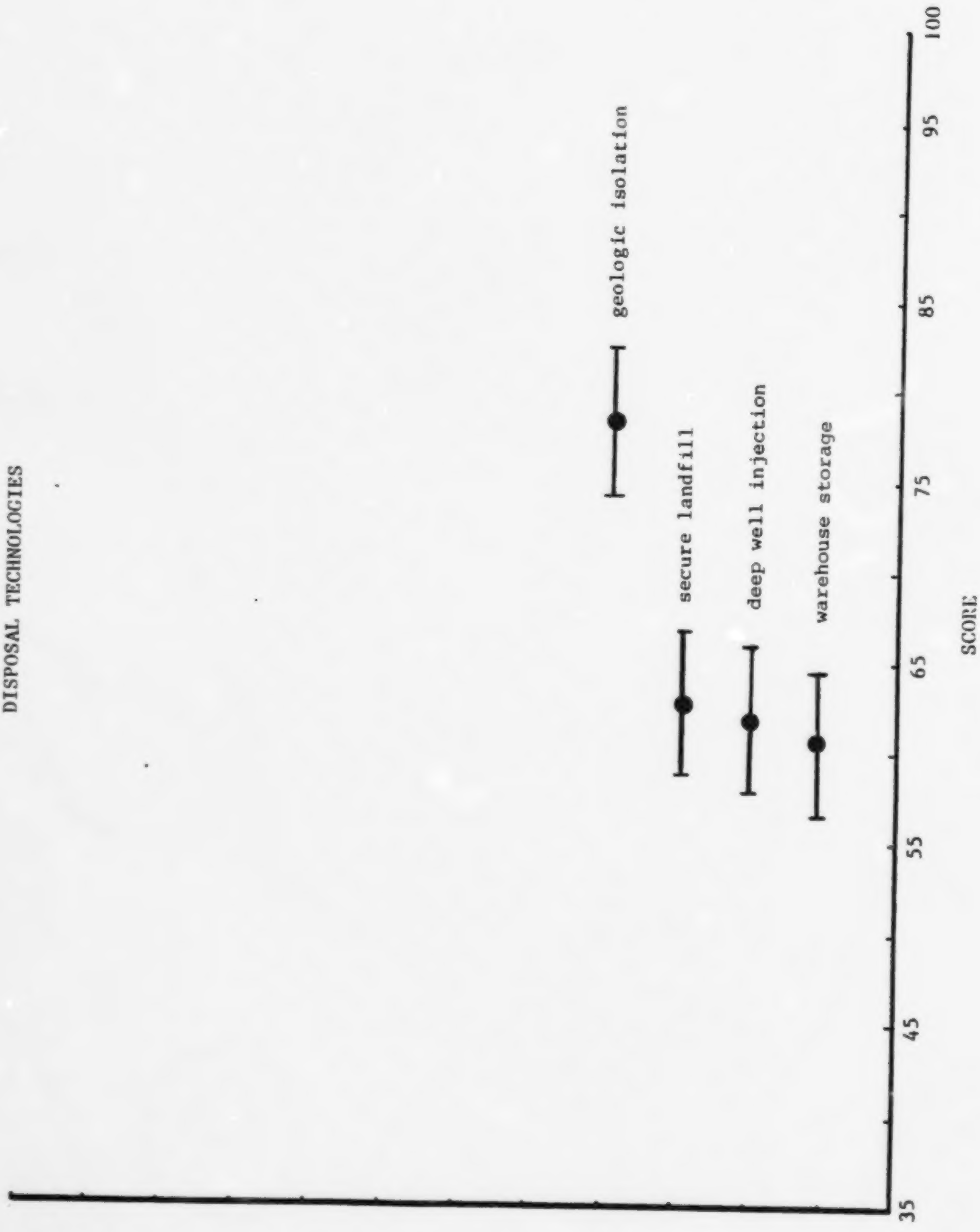


Figure D.7
DISPOSAL TECHNOLOGIES



- The Effect of Individual Criteria Scores

The effect of the scoring of individual criteria on the technology ranking is shown in Table D.11. The first two columns give the order of the technologies based on the total score given to each technology. Each subsequent column gives the order in each category based on the total score minus the score for one criterion. The column "Order: no abnormal events", for example, gives the order of technologies based on the total score minus the score for abnormal events. If the order for a technology changes by more than one place when a criterion is subtracted out, that criterion made an important contribution to the technology ranking (i.e., the technology is sensitive to that criterion). Orders which are different from the total score order by 2 or more are starred (*) in Table D.11 (unless the technology scored the lowest in both categories).

Several observations can be made from Table D.11.

1. Each of the highest scoring technologies in each category except for disposal is insensitive to any one criterion. This means that the highest scoring technologies performed well for all the criteria.

2. Technologies were least sensitive to the criteria "minimize effect of normal events," "maximize operational flexibility," and "minimize cost."

3. Technologies were most sensitive to the abnormal events and operational reliability criteria. These two criteria had the greatest point difference between the lowest possible score for the criterion and the highest possible score (27 and 9 for abnormal events and operational reliability, respectively).

Table D.11

CRITERIA ANALYSIS

Technology	order: total score	order: no abnormal events	order: no normal events	order: no input flexibility	order: no operation flexibility	order: no operation reliability	order: no technical reliability	order: no cost
BIOLOGICAL								
activated sludge/ powdered act. carbon	1	1	1	1	1	1	1	1
activated sludge	2	3	3	1	2	2	2	2
rotating bio contact	3	4	4	2	3	2	3	3
anaerobic digestion	4	5	*2	4	4	3	4	4
fluid bed contactor	5	6	5	*3	5	4	*3	5
trickling filter	5	6	5	*3	5	4	*3	5
land treatment	6	*2	5	6	6	5	5	6
waste stab. pond	6	*2	6	5	6	5	5	6
PHYSICAL								
centrifugation	1	2	1	1	1	2	1	*3
electrodialysis	2	*4	3	2	2	1	*4	*4
filtration	2	2	2	3	2	*4	2	*4
reverse osmosis	2	*4	3	2	2	1	*4	*4
solidification	2	*4	2	3	2	*6	2	1
floc/sedimentation	3	3	4	4	3	*5	3	2
emulsion breaking	4	*1	*6	5	4	*7	5	5
carbon adsorption	5	5	5	4	5	*8	6	4
resin adsorption	5	5	5	4	5	*8	6	4
ultrafiltration	6	*4	6	6	6	*3	7	6
air stripping	7	*2	8	6	7	9	7	7
evaporation	7	*2	7	6	7	9	9	6
dissolved air float.	8	*6	7	8	8	10	9	8
steam stripping	9	*5	9	7	9	11	8	9
solvent extraction	10	*4	10	9	10	12	10	10
CHEMICAL								
ion exchange	1	2	1	1	1	1	1	1
neutralization	1	1	2	1	1	1	2	1
precipitation	2	3	3	2	2	2	2	2
chromium reduction	3	*5	4	3	3	3	3	3
chemical oxidation	4	4	5	4	4	5	4	4
dehalogenation	5	5	6	4	5	6	5	4
wet air oxidation	6	6	7	5	5	*4	6	5
THERMAL								
liquid injection	1	1	1	1	1	1	1	1
rotary kiln incin	2	2	2	2	2	2	2	2
fluidized bed incin	3	3	3	2	3	3	3	3
pyrolysis	3	3	3	2	3	3	3	3
DISPOSAL								
geologic isolation	1	*3	1	1	1	1	1	1
engineered landfill	2	*4	2	2	3	3	2	2
warehouse storage	2	1	2	2	3	3	*4	2
deep well injection	3	2	3	3	2	2	3	3

4. The physical treatment technologies were the most sensitive to the criteria. The abnormal events and operational reliability criteria were the most important in determining the final ordering of the physical treatment technologies.

5. Thermal, chemical, and disposal technologies were least sensitive to the criteria. Only 4 of the 16 technologies in these categories were influenced by this analysis.

6. Several technologies were influenced significantly by only one criterion:

   - Anaerobic digestion scored lower than activated sludge and rotating biological contactor due to the need for a respirator during equipment maintenance.

   - Land treatment and waste stabilization ponds scored poorly primarily due to the possibility of off-site release during an abnormal event (e.g., a flood in excess of the design flood).

   - Carbon adsorption scored better than ultrafiltration due to better operational reliability (low versus high downtime). Similarly, wet air oxidation scored lower than chemical oxidation and dehalogenation since it has a high downtime.

   - Solvent extraction and steam stripping scored low in comparison with other physical treatment technologies since they received the lowest scores in that category for abnormal events.

   - Chromium reduction scored better than chemical oxidation due to a better score for abnormal events.

- Geologic isolation and secure landfill are the highest scoring disposal technologies since they received the highest score for the abnormal events criterion. The high score for geologic isolation in comparison with other disposal technologies was due to a significantly higher score in this criterion.

- Warehouse storage scored as well as secure landfill and higher than deep well injection due to better technical reliability (monitoring).

- The Effect of Weights

Weights were used in the technology ranking system to take into account that some criteria are more important than others. The weights derived for each criterion are given in Figure D.1. The effect of weights on the technology rankings is analyzed in Table D.12.

The technology scores in Table D.12 were calculated using an unweighted scheme for each technology by assigning a +1 if the technology is desirable for a criterion, 0 if the technology is neutral, -1 if the technology is undesirable. Thus, all criterions have the same weight. Under this no weights ranking scheme, the highest score attainable is a +7 (+1 for each of the seven criterions) and the lowest score is a -7. Fractional scores can occur when a criterion has more than one measure. Abnormal events, for example, has four measures. Each measure is scored +.25, 0 or -.25 so that the highest score for the criterion would be +1 and the lowest -1.

As indicated in Table D.12, physical and biological technologies are most influenced by removing the weights, and the order for chemical, thermal and disposal technologies is not affected by the change. Land treatment and waste stabilization ponds, for example, go from

Table D.12

NO WEIGHT

RANKING SYSTEM

Technology	original order	score: no weights	order: no weights
BIOLOGICAL			
activated sludge/ powdered act. carbon	1	.25	1
activated sludge	2	- .75	2
rotating bio contact	3	-1.75	4
anaerobic digestion	4	-1.75	4
fluid bed contactor	5	-2.75	5
trickling filter	5	-2.75	5
land treatment	6	-1.00	*3
waste stab. pond	6	-1.00	*3
PHYSICAL			
centrifugation	1	2.75	2
electrodialysis	2	2.75	2
filtration	2	2.50	3
reverse osmosis	2	2.75	2
solidification	2	1.75	*4
floc/sedimentation	3	1.50	*5
emulsion breaking	4	3.25	*1
carbon adsorption	5	.50	*7
resin adsorption	5	.50	*7
ultrafiltration	6	2.50	*3
air stripping	7	1.75	*4
evaporation	7	1.75	*4
dissolved air float.	8	.75	*6
steam stripping	9	.75	*6
solvent extraction	10	- .50	8
CHEMICAL			
ion exchange	1	4.75	2
neutralization	1	5.50	1
precipitation	2	4.00	3
chromium reduction	3	- .50	4
chemical oxidation	4	- .50	4
dehalogenation	5	-2.00	5
wet air oxidation	6	-2.00	5
THERMAL			
liquid injection	1	-2.00	1
rotary kiln incin	2	-3.00	2
fluidized bed incin	3	-4.00	3
pyrolysis	3	-4.00	3
DISPOSAL			
geologic isolation	1	1.50	1
engineered landfill	2	1.50	1
warehouse storage	2	.50	2
deep well injection	3	.00	3

being the lowest biological technologies when weights are used to being the third highest when weights are not used. This indicates that these technologies scored poorly on the more heavily weighted criteria in comparison with the other biological technologies. None of the highest scoring technologies in a category was significantly affected by removing the weights.

Conclusions

The analyses presented above indicate that the technology rankings are relatively insensitive to modifications in the ranking system. This is especially true for the technologies which score the highest in each category. The rankings of physical and biological treatment technologies are most influenced by modification in the ranking system. Chemical reduction, wet air oxidation, geologic isolation, engineered landfill, and warehouse storage are also sensitive to the ranking system. The ranking of these technologies should be considered less firm than technologies which are less sensitive to ranking system variations.

TECHNOLOGY SUMMARIES

The following pages summarize the scoring and system development information for the technologies used in Systems 1-4. Quantity discharged and quantity transferred to other technologies are estimated based on assumed performance of the generic technology. Actual performance may vary depending on specific technology design and the nature of the wastes received. Capital and operating costs are given based on the technology size given under Economic Factors. All costs are in December 1985 Canadian dollars. Capital costs are incremental costs for adding a technology to the system and are used only in estimating total capital costs for each system.

ACTIVATED SLUDGE/POWDERED ACTIVATED CARBON

Category	Technology Characteristics	Factor Score
Inputs	225, 226	UCD Groups: 2 Variations: 5
Discharges	Aqueous stream with trace organics[a] 1,000 kg/tonne Gaseous emission from carbon regeneration 800 kg/tonne	Off-site discharge: 5
Transfers to Other Technologies	Sludge to dewatering or incineration 160 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of uncontrolled gaseous emissions; exposure to on-site personnel possible prior to emergency response. Off-site: possibility of small volume air release; no off-site exposure due to buffer zone, dilution and emergency response. No special personal protective equipment required.	On-site release: 2 On-site consequences: 2 Off-site release: 5 Off-site consequences: 8 Special equipment: 7
Operations Factors	Simple operation in comparison with other biological treatment technologies. Periodic monitoring for COD. Not easily upset by minor constituents. Low unscheduled downtime. Must be operated continuously.	Ease of operation: 6 Type of operation: 3 Type of monitoring: 3 Downtime: 9
Economic Factors	2,020 tonne/yr $46,500 Capital $20/tonne	Cost: 5

Notes: [a] Liquid effluent that is released if permissible, after analysis, or transfer to solidification, if zero discharge. Batch discharge assumed for scoring purposes.

CENTRIFUGATION

Category	Technology Characteristics	Factor Score
Inputs	141, 142, 145, 211, 212, 214, 215, 221, 251, 283, 288, 417, 431, 433, 441, 443, 445, 454, 455, 523	UCD Groups: 6 Variations: 5
Discharges	Organics--liquid stream to incineration 0.9 tonne/tonne Inorganics--aqueous stream to discharge 0.9 tonne/tonne	Off-site discharge: 7
Transfers to Other Technologies	Inorganic Cake to solidification 160 kg/tonne Organic Cake to incineration 100 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of small spill which is contained prior to exposure of on-site personnel. Off-site: no possibility of off-site release of contaminants since no air releases and any liquid release is contained on-site. Special personal protective equipment may be required for maintenance.	On-site release: 5 On-site consequences: 7 Off-site release: 11 Off-site consequences: 8 Special equipment: 3
Operational Factors	Simple operation in comparison with other physical technologies. Period monitoring of percent solids. Moderate unscheduled downtime. Not easily upset by minor constituents.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 3 Downtime: 7
Economic Factors	50,000 t/a $230,000 capital $2/tonne	Cost: 8

CHEMICAL OXIDATION

Category	Technology Characteristics	Factor Score
Inputs	143, 146, 147, 444	UCD Groups: 5 Variations: 5
Discharges	Aqueous stream[a] 1.5 tonne/tonne	Off-site discharge: 5
Transfers to Other Technologies	Metal-containing sludge to solidification; 150 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of uncontrolled gaseous emissions; exposure to on-site personnel possible prior to emergency response. Off-site: possibility of large or highly dangerous air release; exposure to off-site populations possible prior to emergency response. Protective clothing may be required for reagents handling.	On-site release: 2 On-site consequences: 4 Off-site release: 0 Off-site consequences: 2 Special equipment: 3
Operational Factors	Complex operation in comparison with other chemical technologies. Periodic monitoring for reactive anions. Batch process. Not easily upset by minor constituents. Low unscheduled downtime.	Ease of operation: 4 Type of operation: 8 Type of monitoring: 3 Downtime: 9
Economic Factors	3,100 t/a $320,000 Capital $35/tonne	Cost: 5

Notes: [a] Liquid effluent that is released if permissible, after analysis, or transfer to solidification, if zero discharge. Batch discharge assumed for scoring purposes.

CHEMICAL REDUCTION

Category	Technology Characteristics	Factor Score
Inputs	143, 251	UCD Groups: 2 Variations: 5
Discharges	Aqueous stream with less than 1 ppm Cr^{+6} and 1 to 2 ppm total Cr and other ions[a] 1.2 tonne/tonne	Off-site discharge: 5
Transfers to Other Technologies	Sludge containing $Cr(OH)_3$ to solidification 10 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of uncontrolled gaseous emissions; exposure to on-site personnel possible prior to emergency response. Off-site: no possibility of off-site release of contaminants since no air releases and any liquid release is contained on-site. Protective clothing may be required for waste handling.	On-site release: 2 On-site consequences: 4 Off-site release: 11 Off-site consequences: 8 Special equipment: 3
Operational Factors	Complex operation in comparison with other chemical technologies. Batch process. Low unscheduled downtime. Periodic monitoring for Cr VI level. Not easily upset by minor constituents.	Ease of operation: 4 Type of operation: 8 Type of monitoring: 3 Downtime: 9
Economic Factors	2,000 tonne/yr $150,000 Capital $35/tonne	Cost: 5

Notes: [a]Liquid effluent that is released if permissible, after analysis, or transfer to solidification, if zero discharge. Batch discharge assumed for scoring purposes.

EMULSION BREAKING

Category	Technology Characteristics	Factor Score
Inputs	281, 282, 283, 289	UCD Groups: 5 Variations: 5
Discharges	None	Off-site discharge: 7
Transfers to Other Technologies	Acidic oily solids to incineration 250 kg/tonne Acidic aqueous stream to neutralization 800 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of large spill which is contained prior to exposure of on-site personnel. Off-site: possibility of small volume air release; no off-site exposure due to buffer zone, dilution, and emergency response. No special personal protective equipment required.	On-site release: 2 On-site consequences: 7 Off-site release: 5 Off-site consequences: 8 Special equipment: 7
Operational Factors	Simple operation in comparison with other physical technologies. Batch operation. Low unscheduled downtime. Periodic monitoring (visual inspection).	Ease of operation: 6 Type of operation: 8 Type of monitoring: 3 Downtime: 9
Economic Factors	4,000 t/a $80,000 Capital $20/tonne	Cost: 5

ENGINEERED LANDFILL

Category	Technology Characteristics	Factor Score
Inputs[a]	151, 152, 165, 167, 416, 417, 431, 433, 441, 443, 445, 519, 513, 518	UCD Groups: 6 Variations: 5
Discharges	None	Off-site discharge: 7
Transfers to Other Technologies	Run-off to biological or phys/chem treatment 400 kg/tonne Leachate to biological or phys/chem treatment 1.1 tonne/tonne	
Health, Safety and Environmental Factors	On-site: possibility of contact with waste; exposure prevented since workers already in protective gear. Off-site: possibility of release of large quantity of contaminants during flood in excess of design flood; exposure to off-site population possible. Protective clothing may be required for waste handling	On-site release: 2 On-site consequences: 7 Off-site release: 0 Off-site consequences: 2 Special equipment: 3
Operational Factors	Simple operation in comparison with other technologies. Batch process. Periodic monitoring (groundwater sampling). Low unscheduled downtime.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 3 Downtime: 9
Economic Factors	100,000 t/a $10,690,000 Capital $75,tonne	Cost: 5

[a] OWMC would use engineered landfill only for treated, solid residues.

EVAPORATION

Category	Technology Characteristics	Factor Score
Input	141, 142,145	UCD Groups: 2 Variations: 5
Discharges	Air emissions of vapors containing moisture, volatile organics, and trace quantities of inorganics 850 kg/tonne	Off-site discharge: 4
Transfers to Other Technologies	Brine concentrate or wet solids to solidification 150 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of uncontrolled gaseous emissions; exposure to on-site personnel possible prior to emergency response. Off-site: possibility of small volume air release; no off-site exposure due to buffer zone, dilution and emergency response. No special personal protective equipment required.	On-site release: 2 On-site consequences: 4 Off-site release: 5 Off-site consequences: 8 Special equipment: 7
Operational Factors	Simple operation in comparison with other physical technologies. Batch process. Low unscheduled downtime. Automatic monitoring for temperature.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 7 Downtime: 9
Economic Factors	75,000 t/a $4,730,000 Capital $20/tonne	Cost: 5

FILTRATION

Category	Technology Characteristics	Factor Score
Input	141, 142, 145, 251, 417, 431, 433, 441, 443, 445, 454, 455	UCD Groups: 6 Variations: 5
Discharges	Aqueous stream with dissolved metals, salts 900 kg/tonne	Off-site discharge: 7
Transfers to Other Technologies	Inorganic Filter cake to solidification 100 kg/tonne 100 kg/tonne Organic filter cake to incineration 100 kg/tonne Organic--liquid stream to 0.9 t/t	
Health, Safety and Environmental Factors	On-site: possibility of uncontrolled gaseous emissions; exposure to on-site personnel possible prior to emergency response. Off-site: no possibility of off-site release of air since no air releases and any liquid release is contained on-site. Special personal protective equipment may be required for maintenance.	On-site release: 2 On-site consequences: 7 Off-site release: 11 Off-site consequences: 8 Special equipment: 3
Operational Factors	Moderately complex in comparison with other physical technologies. Periodic monitoring for percent solids. Moderate unscheduled downtime. Not easily upset by minor constituents. Batch process.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 3 Downtime: 7
Economic Factors	50,000 t/a $370,000 Capital $2/tonne	Cost: 8

FLOCCULATION & SEDIMENTATION

Category	Technology Characteristics	Factor Score
Input	141, 142, 145, 251, 262, 288, 416, 417, 431, 433, 441, 443, 445, 454, 455	UCD Groups: 6 Variations: 5
Discharges	Aqueous stream with metals, salts, or organics along with small quantities of suspended solids to incineration or discharge 900 kg/tonne	Off-site discharge: 7
Transfers to Other Technologies	Slurry containing organics, inorganics, and metals to dewatering 180 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of large spill which is contained prior to exposure of on-site personnel. Off-site: no possibility of off-site release of air since no air releases and any liquid release is contained on-site. No special personal protective equipment required.	On-site release: 2 On-site consequences: 7 Off-site release: 11 Off-site consequences: 8 Special equipment: 7
Operational Factors	Batch process. Small quantities of certain materials will inhibit sedimentation periodic monitoring for suspended particulates. Moderate unscheduled downtime. Moderately complex in comparison with other physical technologies.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 3 Downtime: 7
Economic Factors	2,000 t/a $860,000 Capital $40/tonne	Cost: 3

NEUTRALIZATION

Category	Technology Characteristics	Factor Score
Input	113, 123	UCD Groups: 2 Variations: 5
Discharges	None	Off-site discharge: 7
Transfers to Other Technologies	Aqueous stream with pH 6-9 to solidification 1 tonne/tonne	
Health, Safety and Environmental Factors	On-site: possibility of large spill which is contained prior to exposure of on-site personnel. Off-site: no possibility of off-site release of contaminants since no air releases and any liquid release is contained on-site. No special personal protective equipment required.	On-site release: 2 On-site consequences: 7 Off-site release: 11 Off-site consequences: 8 Special equipment: 7
Operational Factors	Batch process. Low unscheduled downtime. Not easily upset by minor constituents. Automatic monitoring of pH. Simple operation in comparison with other chemical technologies.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 7 Downtime: 9
Economic Factors	21,000 t/a $150,000 Capital $10/tonne	Cost: 8

PRECIPITATION

Category	Technology Characteristics	Factor Score
Input	111, 112, 121, 122, 131, 132, 133, 141, 142,	UCD Groups: 6 Variations: 5
Discharges	Aqueous stream with pH 6-9 1.05 tonne/tonne	Off-site discharge: 7
Transfers to Other Technologies	Filter cake with metals and salts to dewatering 150 kg/tonne	
Health, Safety and Environmental Factors	On-site: possibility of large spill which is contained prior to exposure of on-site personnel. Off-site: no possibility of off-site release of contaminants since no air releases and any liquid release is contained on-site. No special personal protective equipment required.	On-site release: 2 On-site consequences: 7 Off-site release: 11 Off-site consequences: 8 Special equipment: 7
Operational Factors	Simple operation in comparison with other chemical technologies. Batch process. Periodic monitoring for dissolved solids. Low unscheduled downtime. Not easily upset by minor constituents.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 3 Downtime: 9
Economic Factors	20,000 t/a $210,000 Capital $10/tonne	Cost: 8

ROTARY KILN INCINERATION

Category	Technology Characteristics	Factor Score
Input	211, 212, 213, 214, 215, 216, 217, 221, 222, 223, 224, 225, 226, 227, 228, 241, 242, 243, 245, 247, 248, 252, 254, 257, 258, 261, 262, 263, 264, 281, 282, 283, 284, 285, 286, 288, 289, 416, 446, 447, 454, 455, 512, 513, 521, 523, 528, 531, 532	UCD Groups: 7 Variations: 5
Discharges	Air emissions with trace particulate and organic species 14 tonne/tonne	Off-site discharge: 4
Transfers to Other Technologies	Solid residue from semi-wet scrubber to solidification 85 kg/tonne Solid residue from waste (ash) to landfill 50 kg/tonne Recoverable heat from incinerator 12.0 GJ/tonne	
Health, Safety and Environmental Factors	On-site: possibility of uncontrolled gaseous emissions; exposure to on-site personnel possible prior to emergency response. Off-site: possibility of large or highly dangerous air release; exposure to off-site populations possible prior to emergency response. Special personal protective equipment may be required for maintenance.	On-site release: 2 On-site consequences: 4 Off-site release: 0 Off-site consequences: 2 Special equipment: 3
Operational Factors	Complex operation in comparison with other chemical technologies. Batch process. High unscheduled downtime. Automatic monitoring for temperature. Not easily upset by minor constituents. Must be operated continuously.	Ease of operation: 4 Type of operation: 3 Type of monitoring: 7 Downtime: 0
Economic Factors	36,000 t/a $34,610,000 Capital $105/tonne	Cost: 5

SOLIDIFICATION

Category	Technology Characteristics	Factor Score
Input	141, 142, 145, 151, 152, 165, 167, 417, 431, 433, 441, 443, 444, 445, 454, 455, 518	UCD Groups: 6 Variations: 5
Discharges	None	Off-site discharge: 7
Transfers to Other Technologies	Solidified wastes to landfill 1.6 tonne/tonne	
Health, Safety and Environmental Factors	On-site: possibility of small spill which in contained prior to exposure of on-site personnel. Off-site: no possibility of off-site release of contaminants since no air releases and any liquid release is contained on-site. Protective clothing may be required for solids handling.	On-site release: 5 On-site consequences: 7 Off-site release: 11 Off-site consequences: 8 Special equipment: 3
Operational Factors	Simple operation in comparison with other physical technologies. Batch process. Easily upset by organics or certain salts in wastes. Low unscheduled downtime. Periodic monitoring for slump, leachability.	Ease of operation: 6 Type of operation: 8 Type of monitoring: 3 Downtime: 9
Economic Factors	50,000 t/a $610,000 Capital $35/tonne	Cost: 3

SOLVENT EXTRACTION

Category	Technology Characteristics	Factor Score
Input	227, 228, 288	UCD Groups: 5 Variations: 5
Discharges	None	Off-site discharge: 7
Transfers to Other Technologies	Extracted waste to incineration 50 kg/tonne	
	Aqueous stream with trace organics to activated sludge/powdered activated carbon	
Health, Safety and Environmental Factors	On-site: possibility of fire or explosion; exposure to on-site personnel possible prior to emergency response. Off-site: possibility of large or highly dangerous air release; exposure to off-site populations possible prior to emergency response. May require respirator during equipment maintenance.	On-site release: 2 On-site consequences: 4 Off-site release: 0 Off-site consequences: 2 Special equipment: 3
Operational Factors	Complex operation in comparison with other physical technologies. Continuous monitoring with operator support for dissolved organics. Not easily upset by minor constituents. Batch process. Low unscheduled downtime.	Ease of operation: 4 Type of operation: 8 Type of monitoring: 6 Downtime: 9
Economic Factors	100 t/a $50,000 Capital $75/tonne	Cost: 3